Gulzar Ahmad Nayik
Amir Gull *Editors*

Antioxidants in Fruits: Properties and Health Benefits

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This book is dedicated to my
beloved daughter Eidain Hoor Binti Gulzar

Preface

Fruits are one of the most important indicators of diet quality and have protective effects against many of chronic diseases such as cardiovascular diseases, obesity, and various types of cancer. To improve fruit consumption, it is necessary to know and understand the constituents of fruits. Considering the importance of knowledge and awareness as one of the determinants of fruit consumption, this book provides comprehensive knowledge on botanical description and nutritional and nutraceutical properties of a wide range of commonly consumed fruits in many parts of world. This book will also cover the characterization of the chemical compounds which are responsible for antioxidant proprieties of various fruits.

This book has been designed especially for college/university students, research scholars, academicians, pomologists, as well to agricultural scientists. Researchers, scientists, and others working in various fruit processing industries and other horticultural departments will also find the comprehensive information relevant to their work.

Shopian, India — Gulzar Ahmad Nayik
Srinagar, India — Amir Gull

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Editors and Contributors

About the Editors

Gulzar Ahmad Nayik is currently working as Assistant Professor in the Department of Food Science & Technology, Govt. Degree College, Shopian, J&K, India. He completed his Master's Degree in Food Technology from IUST, Awantipora, J&K, India, and Ph.D. from SLIET, Punjab, India. He has published 44+ peer-reviewed research/review papers, many book chapters, 1 textbook, and delivered a number of presentations in various national and international conferences, seminars, workshops, and webinars. Dr. Nayik was shortlisted twice for the prestigious INSPIRE-Faculty Award in 2017 and in 2018 by the Indian National Science Academy, New Delhi. Dr. Nayik was nominated for India's prestigious National Award (INSA Medal for Young Scientists-2019–20). Dr. Nayik was also selected as Young Professional in Ministry of Food Processing Industries, Govt. of India. Dr. Nayik's research activities have been focused on characterizing different high-altitude Indian honeys by analyzing their nutraceutical potential and antiproliferative properties, marker identification for the discrimination of honey, and determining their volatile components and phenolic, flavonoid, mineral, enzymatic, and sugar profile. Dr. Nayik is also serving as Editor, Associate Editor, and Assistant Editor in many journals related to Food Science & Technology. Dr. Nayik is a frequent reviewer of several reputed journals in the area of Food Science and Technology. He is also working as member of various associations like WASET, AFSTI, IFST, IAAS, IAENG, IAJC, ASR, IFERP, and Asian Council of Science Editors. Dr. Nayik is recipient of Top Peer Reviewer Award 2019 from Web of Sciences Group powered by Publons for placing in the top 1% of reviewers in Agricultural Sciences. He is also recipient of International Travel Grant from DST India and MANF from UGC India.

Amir Gull is currently working as Senior Research Fellow in the Department of Food Science & Technology, University of Kashmir, Srinagar, J&K, India. He completed his Master's Degree in Food Technology from Islamic University of Science & Technology, Awantipora, J&K, India, and Ph.D. from Sant Longowal Institute of Engineering & Technology, Longowal, Sangrur, Punjab, India. Dr. Gull has published many peer-reviewed research papers and review papers in reputed journals. He has also published few book chapters and delivered a number of presentations in many national and international conferences. Dr. Gull's main research activities include developing functional food products from millets. Dr. Gull is also serving as editorial board member and reviewer of several journals. He is also an active Member of the Association of Food Scientist and Technologist of India.

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1 Natural Antioxidants: Assays and Extraction Methods/Solvents Used for Their Isolation

Ajay Sharma, Garima Bhardwaj, Jyoti Gaba, and Damanjit Singh Cannoo

Abstract

The present chapter aims at providing a brief knowledge regarding plant-based secondary metabolites which act as natural antioxidants (NAs) (viz., flavonoids, phenolic acids, stilbenes, coumarins, lignans, tannins, lignins, alkaloids, sulfur compounds, and essential oils) their mode of action, methods and solvents used for their isolation, and various techniques (in vitro and in vivo) used for the assessment of their antioxidant potential. Apart from this, the chapter also provides a brief knowledge concerning oxidative stress (OS), free radicals (FRs), reactive nitrogen species (NOS), reactive oxygen species (ROS), biological roles of FRs/reactive species (RS), and various routes of their production. The oxidative stress is a situation, where the quantity of FRs/RS in the body of an organism surpasses the homeostatic equilibrium of indigenous antioxidants and FRs/RS. This oxidative stress condition is the cause of more than hundred types of ailment in living beings. The natural antioxidants retard or slow down the oxidation of other biomolecules/molecules and help to alleviate the oxidative stress condition. Further, these NAs are economic, eco-friendly, nontoxic as compared to synthetic antioxidants, and easily accessable to common people. These NAs can be attained from any part of the plant, viz., roots, rhizomes, stems, bark, leaves, flowers, and fruits. The plant-based natural antioxidants are also well known for their wide variety of therapeutic potential.

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Keywords

Oxidative stress · Secondary metabolites · Polyphenols · Natural antioxidants · In vitro and in vivo antioxidant assays

1.1 Introduction

Secondary metabolites (SMs) of plant origin have been used from ancient times as therapeutic agents for the cure of many diseases, flavoring agent, food preservatives, insect repellent, etc. People in tribal areas of countries like India, China, Bangladesh, Bhutan, Nepal, Pakistan, Egypt, etc. largely used these SMs as medicines, which formed the basis of the conventional medical systems (Ravishankar and Shukla 2007; Ekor 2014; Sharma et al. 2019). On the other hand, nowadays most of the synthetic therapeutic agents used for the cure of various kinds of illnesses have many side effects and cause many serious health issues. Due to these reasons in the present scenario, strategies have been made to replace synthetic chemicals with SMs of plant origin because the latter have less or no side effects and are cost-effective, eco-friendly, biodegradable, and nontoxic in nature.

Presently, the interest of researchers on natural compounds (mainly polyphenolics) which exhibit antioxidant properties and beneficial to human beings as food additive or as specific preventive pharmaceuticals is growing at a fast pace (Pinelo et al. 2005; Petlevski et al. 2013; Bettaieb et al. 2010). As a result, natural antioxidants have become a vital part of preservation technology and modern health care. The various crude extracts isolated from different parts of plants such as roots, stem, bark, leaves, and flowers are rich in polyphenolics and are progressively used in the food and cosmetic industry as these check the oxidative breakdown of lipids and help to improve the quality of food and cosmetic products. Due to this, polyphenolics and other antioxidant constituents isolated from plants have made scientists, manufacturers (food and cosmetic products), and consumers aware, since the drift of the future is toward functional food and superior cosmetic products with definite health effects in order to maintain good health (Sen et al. 2010; Nunes et al. 2012; Nile et al. 2017; Bhardwaj et al. 2019).

1.2 Medicinal Plants and Antioxidant Potential

Apart from their own endogenous self-sufficient antioxidant defense system, human beings also take antioxidants from external sources through diet in order to maintain the internal balance between reactive species (FRs, free radicals; ROS, reactive oxygen species; and RNS – reactive nitrogen species) and antioxidants during different adverse conditions (stress, hypertension, smoking, heavy physical workout, and various diseased conditions) that encourage the production of the former in the human body. The external sources (mainly plant based) have varying amounts of antioxidants, which are proficient to prevent or retard the oxidation of various bioactive compounds in the body (Sen et al. 2010; Nunes et al. 2012).

Aromatic medicinal, herbal, and other higher plants contain various classes of SMs (phenolic acid, flavonoids, tannins, phytosterol, terpenoids, saponins, etc.). These classes of SMs have been well known for their antioxidant potential (Oluwaseun and Ganiyu 2008; Sen et al. 2010; Patial et al. 2019). The extracts isolated from herbal and aromatic medicinal plants are taken as decoctions or infusions, owing to their remedial actions. Further, the bioactive compounds present in these plants are a part of the physiological metabolism of living flora due to which they are supposed to have a superior compatibility with human body (Sen et al. 2010; Nile et al. 2017).

The different medicinal and herbal plants might serve not merely as flavoring agents but also as eco-friendly food antioxidants and nutrient supplements. These natural antioxidants also help to prevent the deterioration of various foodstuff products. The use of SMs (phytochemicals) as a drug (antioxidant) to treat various disorders which result in oxidative stress conditions and to scavenge the FRs and reactive species has now clinically been proved as less toxic and more efficient as compared to the existing synthetic drugs and antioxidants (Wannes et al. 2010; Sen et al. 2010; Petlevski et al. 2013). Many synthetic antioxidants (phenolics with alkyl substituents) such as butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), tertiary butyl hydroquinone (TBHQ), and propyl gallate have been used from the beginning of this century as additives to protect and stabilize various food products for flavor, freshness, nutritive value, and color. However, various studies on the use of synthetic antioxidants have revealed that these are toxic in nature (cause cancer) and are not fit for long-term consumption (Wanasundara and Shahidi 1998; Bouayed and Bohn 2010; Nunes et al. 2012; Muniyandi et al. 2017). Hence, it is an aggressive need of present time to use SMs/phytochemicals of plant origin as drug/antioxidants to cure and prevent oxidative stress and related diseases. Till date, a large number of plant species have been analyzed as sources of potent and safe bioactive SMs which are mainly responsible for the antioxidant potential of studied plant species (Nile et al. 2017; Muniyandi et al. 2017).

Till date, approximately 27,000 alkaloids; 2000 lactins and peptides; 700 non-protein amino acids; 150 glucosinolates; 100 amines; 60 cyanogenic glycosides; 3000 monoterpenes; 5000 sesquiterpenes; 2500 diterpenes; 5000 triterpenes, steroids, and saponins; 500 tetraterpenes; 2000 phenylpropanoids (coumarins and lignans); 4000 flavonoids, anthocyanins, and tannins; 800 polyketides; 1500 polyacetylenes; and 600 carbohydrates and organic acids have been characterized and identified from various plant species (Wink 2015). All these classes of SMs act as natural antioxidants, but the polyphenolic compounds are the major ones (Ignat et al. 2011; Dzialo et al. 2016; Nunes et al. 2012; Ganesan and Xu 2017 and references therein).

1.3 Oxidative Stress

"Oxidative stress" is the term used to represent the state of any disturbance in the equilibrium of reactive species (FRs, ROS, and RNS) and antioxidants in favor of the former as a result of various factors, viz., aging, trauma, inflammation, pollution, poor diet, cold, infections, increase in oxidative metabolism, strenuous physical activity, radiation, toxicity, and drug actions (Sies 1985; Ullah et al. 2016). In this state, generally there is excess production and/or inadequate elimination of highly reactive molecules like FRs, ROS, and RNS from the cell (Johansen et al. 2005; Tian et al. 2007). Oxidative stress conditions may lead to the offensive functioning of healthy cell by damaging the biomolecules (like RNA, DNA, proteins, carbohydrates, and lipids) and ultimately lead to the death of the cell. Oxidative stress conditions are supposed to play a crucial role in the aging process and have been the vital reason for the onset of over 100 kinds of diseases (Fig. 1.1) (Agarwal and Prabakaran 2005; Dufor et al. 2007; Sharma et al. 2010; Sen et al. 2010; Rahal et al. 2014; Ullah et al. 2016).

1.3.1 Free Radicals (FRs), Reactive Oxygen Species (ROS), and Reactive Nitrogen Species (RNS)

A moiety or molecules that have one or more than one unpaired electron in its outermost molecular/atomic orbital are known as FRs. The FRs are short-lived and very reactive in nature and can exist independently. These FRs pass their unpaired electrons to living cells and result in the oxidation of cell components and molecules,

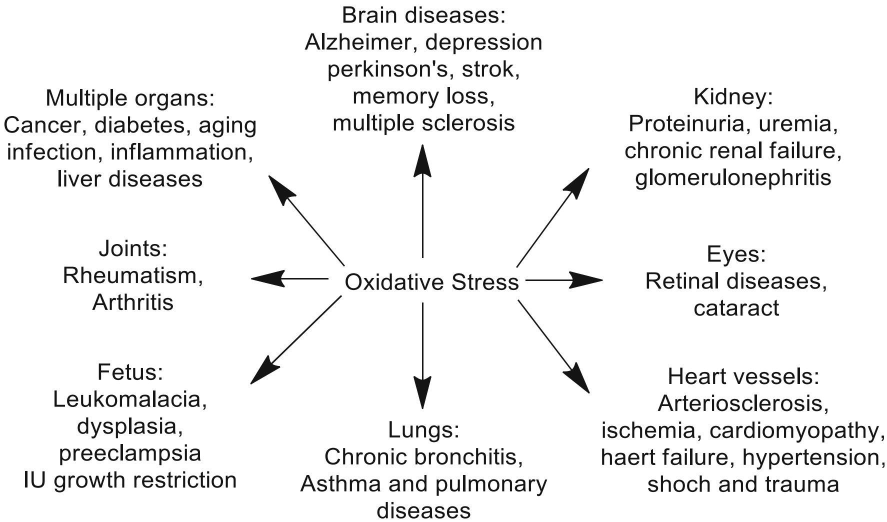

Fig. 1.1 Various diseases associated with oxidative stress condition

which leads to the abnormal functioning of the cells and finally to death. On the other hand, the non-radical reactive species (specially RNS and ROS) do not have odd electrons but are capable to lead the free radical reactions easily in living beings, i.e., oxidation of various biomolecules (Halliwell and Gutteridge 1999; Halliwell and Gutteridge 2007). The reactive species generated from nitrogen and oxygen are described as the main classes of radical/reactive species produced in living beings. These radical/reactive species act as key intermediates in various natural processes going on in the body of living beings such as cytotoxicity, neurotransmission and control of vascular tone, etc. (Sharma et al. 2010; Sen et al. 2010; Erzsebet et al. 2016; Ullah et al. 2016 and references therein). The various radical/reactive species are classified as follows (Erzsebet et al. 2016; Halliwell and Gutteridge 2007):

- Free radical species: hydroperoxyl radical ($HOO^{\bullet}$), superoxide radical ($O2^{\bullet -}$), hydroxyl radical ($HO^{\bullet}$), lipid radical ($L^{\bullet}$), lipid peroxyl radical ($LOO^{\bullet}$), peroxyl radical lipid alkoxyl radical ($LO^{\bullet}$), ($ROO^{\bullet}$), nitrogen dioxide ($NO_2^{\bullet}$), nitric oxide ($NO^{\bullet}$), protein radical ($P^{\bullet}$), and thiyl radical ($RS^{\bullet}$)
- Non-free radical reactive species: ozone (O_3), hydrogen peroxide (H_2O_2), singlet oxygen ($^1O_2$), dinitrogen trioxide (N_2O_3), lipid hydroperoxide (LOOH), hypochlorous acid (HOCl), nitrous oxide (N_2O), peroxynitrite ($ONOO^-$), peroxynitrous acid (ONOOH), nitryl chloride (NO_2Cl), and nitrous acid (HNO_2)

1.3.2 Biological Roles of Free Radical/Reactive Species

FRs and other reactive species (ROS and RNS) are known to be essential evil, as they play crucial role in the beginning and evolution of life on the earth. Inside the cell, they play substantial part in activating the different signaling pathways like mitogen-activated protein kinase (MAPK) and extracellular signal-regulated kinase (ERK) pathways that modify gene expression, as well as initiate cell death in association with superoxide dismutase. Further, these are also able to react with nucleic acids, proteins, membrane lipids, various enzymes, and other small molecules, leading to cellular damage. For example, RNS produced by neurons and macrophages act as neurotransmitters and mediators of immunity, respectively. These are also known for thrombosis, angiogenesis, vascular tone, and leukocyte adhesion. Similarly, ROS and RNS are known to play a vital role in single transduction, gene transcription, and regulation of other metabolisms in cell (Halliwell and Gutteridge 2007; Ullah et al. 2016; Erzsebet et al. 2016 and references therein).

1.3.3 Production Route of FRs, RNS, and ROS

FRs, RNS, and ROS are generated in the cells and it's surrounded by both exogenous and endogenous substances. These can be generated by different reactions (non-enzymatic) of organic molecules with oxygen, from reactions that are initiated by various ionizing radiations, also from oxidative phosphorylation, and many other

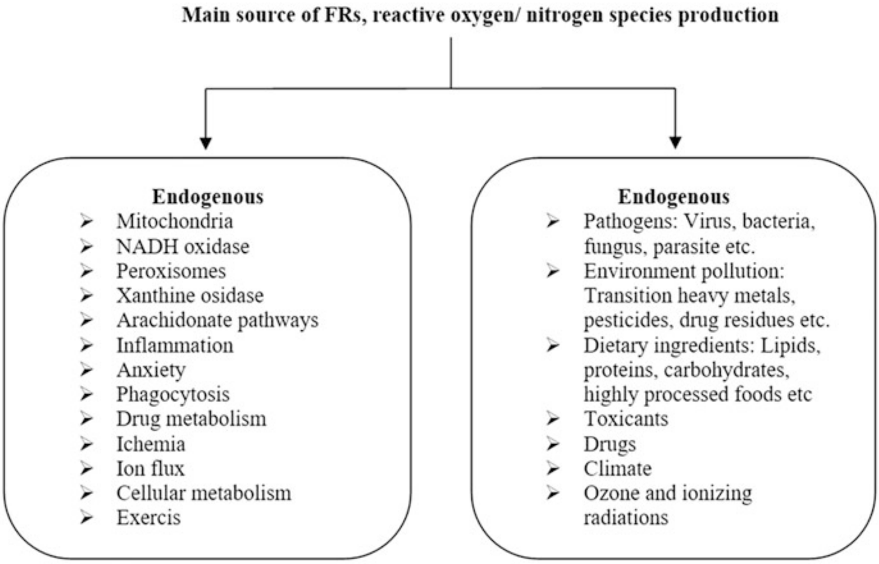

Fig. 1.2 Different routes/sources of FRs/reactive species generation in living beings

metabolic reactions that occur in the mitochondrion. FRs/reactive species are continuously generating in the cell and environment (Rahal et al. 2014; Sen et al. 2010; Ullah et al. 2016 and references therein). The different routes/sources of FRs/reactive species generation are illustrated in Fig. 1.2.

1.4 Antioxidants

Antioxidants are the substances that inhibit or delay the oxidation of a substrate, even when present in minute concentration. These play an important role in protecting the body tissue against the damage caused by oxidative stress conditions. Antioxidants form a barrier against the various reactive species (FRs, ROS, RNS, etc.) which help to delay the onset of various degenerative oxidation processes within the body (Jacob 1995; Sen et al. 2010). In order to protect the cells/organs from the damage caused by FRs/reactive species, the bodies of living beings have developed an extremely complicated and complex antioxidant defense system. This antioxidant defense system has an array of components, which may be endogenous (in vivo synthesized) or exogenous (consumed) in origin (Table 1.1) (Droge 2002; Willcox et al. 2004). These components act interactively and synergistically to offset the ill effects caused by FRs/reactive species or oxidative stress conditions. Hence, these components may be regarded as biomarkers of oxidative stress condition (Sen et al. 2010; Ullah et al. 2016). The SMs isolated from natural sources with FRs, ROS, and RNS scavenging properties might have immense significance as

Table 1.1 Antioxidant defense systems of human beings

Antioxidant defense system	
Endogenous antioxidants	Exogenous antioxidants
	Prime dietary antioxidants from plants and other source
Bilirubin	Flavonols: kaempferol*, quercetin*, myricetin*, etc.
Uric acid	Flavanols: catechin* and proanthocyanidins*
NADH and NADPH	Flavones: apigenin* and luteolin*
Ubiquinone (coenzyme Q 10)	Isoflavones: glycitein* and genistein*
Thiols: glutathione, lipoic acid, and N-acetyl cysteine	Anthocyanidins: pelagonidin* and cyanidin*
Proteins that bind metal: albumin (copper), metallothionein (copper), ceruloplasmin (copper), myoglobin (iron), ferritin (iron), and transferrin (iron)	Flavanones: eriodictyol*, naringenin*, hesperetin*, etc. *and their glucosides
Enzymes: catalase, superoxide dismutase, and glutathione peroxidase	Phenolic acids: caffeic acid, chlorogenic acid, gallic acid, etc.
	Carotenoids: β-carotene, lycopene, zeaxanthin, lutein, etc.
	Vitamins: vitamins E and C
	Trace elements: selenium and zinc

*Glucosides of Flavonoids and phenolic acids

therapeutic agents against several diseases initiated due to oxidative stress conditions (Sen et al. 2010; Muniyandi et al. 2017).

The noble antioxidants must have the following properties (Sen 2003; Sharma et al. 2010):

- They must be effectual at low concentration.
- They must be sufficiently soluble in oxidizable medium/product.
- They must be biodegradable, harmless, and non-nuisance meaning eco-friendly at the effective dose even after prolonged storage.
- Their disintegration product should also be biodegradable, harmless, and non-nuisance.
- They must be tasteless and odorless and should not transmit color to the product.
- They must be effectual and stable over a broad range of pH, temperature, and environmental conditions.
- They must be neutral and chemically uncreative with other components present within the body.

1.4.1 Mode of Action of Antioxidants

Antioxidants neutralize or deactivate the FRs/reactive species frequently before they attack targets in biological cells. Antioxidants act as singlet oxygen quencher, radical scavenger, electron donor, hydrogen donor, peroxide decomposer, metal-chelating agents, and enzyme inhibitor. In intracellular and extracellular environment, both enzymatic and nonenzymatic antioxidants are present which help to neutralize/detoxify/deactivate various FRs and reactive species (ROS and RNS) (Kumar 2011; Niki 2011, 2016 and references therein).

Overall, the antioxidants act by various routes such as the following (Kumar 2011):

- They involve in a variety of chain terminating reactions, e.g., α-tocopherol, and trap the various FRs in lipid phase.
- They react with various ROS and RNS due to which the concentration of these reactive species decreases in the intracellular/extracellular environment, e.g., glutathione.
- They scavenge different kinds of initiating radicals, e.g., superoxide dismutase, that bind to superoxide free radicals and act in the lipid phase.
- They form chelating complex with different transition metal catalysts. These chelating complexes help to eliminate numerous transition metals which are well-known prooxidants, e.g., lactoferrin, ferritin, and transferrin, that keep the oxidative stress in check, whereas albumin and ceruloplasmin keep the concentration of copper in check.

All the organisms have well-developed and complex antioxidant defense/repair systems to check the damage triggered by oxidative stress, but they are unable to prevent the damage completely. Also, nowadays production of FRs, RNS, and ROS in the human body has been increased due to wrong feeding habits, pollution, stress (mental or physical), stressful environment conditions, etc. Owing to this, the interest of researchers from various fields has significantly increased in naturally occurring antioxidants for their use in pharmaceutical, food, and cosmetic products. Further, these naturally occurring antioxidants are safer and have no side effects as compared to synthetic ones, which have mutagenic effects, carcinogenic effects, and many other side effects (Nunes et al. 2012; Muniyandi et al. 2017 and references therein). Furthermore, the synthetic drug taken to cure the various illnesses is capable of generating free radical, which becomes the basis of oxidative stress and ultimately leads to tissue damage. For example, a variety of nonsteroidal anti-inflammatory medications are broadly used for the cure of inflammation, rheumatism, fever, pain, and cardiovascular disease, but their chronic administration results in the generation of FRs and reactive species in human body which may lead to gastrointestinal hemorrhage or perforation, gastric erosions and gastric or duodenal ulceration, etc. (Kamboj 2000; Sen et al. 2010).

The current investigations have shown that the antioxidants isolated from natural sources that have FRs/RNS/ROS scavenging potential might have immense reputation as therapeutic agents against a variety of ailments initiated because of oxidative stress. The phytochemicals isolated from various extracts and essential oils of plant origin were found to be effective scavengers of FRs/RNS/ROS and inhibitors of lipid peroxidation (Muniyandi et al. 2017; Sen et al. 2010 and references therein).

1.4.2 Polyphenols as Natural Antioxidants

Polyphenolic compounds are usually found in every part of edible as well as nonedible plants. Plants synthesized polyphenolic compounds during their normal development and also in response to different infections, wounding conditions, insects, and UV radiation. In plants polyphenolic compounds are mainly synthesized through shikimate (directly provide phenylpropanoids like coumarins and hydroxycinnamic acid) and polyketide or acetate (provide simple phenols and many quinines) pathways. These are mainly derived from tyrosine and phenylalanine which occur commonly in all plants (Naczk and Shahidi 2004). Polyphenolic compounds help to protect the plants from pathogens, oxidative stress, UV radiation, harsh climatic conditions, and grazing (Naczk and Shahidi 2006). Whereas, in the human body polyphenolic compounds act as antioxidant and show various biological properties like anticancer, anti-inflammatory, diabetic, cardioprotective, neuroprotective, osteoprotective, antiasthmatic, antiaging, antiseptic, antihypertensive, cerebrovascular protection, hepatoprotective, cholesterol lowering, antibacterial, antifungal, and antiviral (Nunes et al. 2012; Dzialo et al. 2016; Ganesan and Xu 2017). All these facts are also strongly supported by various epidemiological studies and associated meta-analyses done by various researchers from all over the world (He and Sun 2016; Liu et al. 2014; Grosso et al. 2017; Ganesan and Xu 2017).

Antioxidant potential of polyphenolic compounds is attributed to the presence of reactive functional groups, conjugated double bonds, and their annular structure. The polyphenolics show their antioxidant potential through diverse mechanisms of action such as FRs/RNS/ROS trapping, inhibition of FRs/RNS/ROS formation, scavenging of singlet oxygen, by reduction of chelated metal ions (that assist in the generation of FRs/RNS/ROS) by terminating/interrupting the free radical reactions involving lipid peroxidation, and by shielding/protecting the other molecules having antioxidant activity (Dzialo et al. 2016 and references therein).

At present, the curiosity of scholars in natural constituents (polyphenolics) which exhibit antioxidant activity and supplied to living beings as food preservative or as specific protective pharmaceuticals is escalating gradually. Owing to this, natural antioxidants have become vibrant part of preservation technology and modern health care. The variety of crude extracts isolated from various parts of plants like roots, tuber, bark, stem, cladode, leaves, flowers, and fruits are rich in polyphenolics and are gradually used in food, cosmetic, and pharmaceutical industry as they check the oxidative breakdown of lipids and help to improve the quality of food, cosmetic, and pharmaceutical products. As a result of this, polyphenolics and other natural antioxidants obtained from plants and other natural sources are raising awareness among scientists, manufacturers (food, cosmetic, and pharmaceutical products), and consumers since the drift of the future is toward functional food, superior cosmetics, and pharmaceutical products with definite health-promoting effects in order to uphold good health (Nunes et al. 2012 and references therein).

Nowadays, about 8000 polyphenolic compounds are identified from the plants, which primarily act as antioxidants (Harborne et al. 1999). According the most

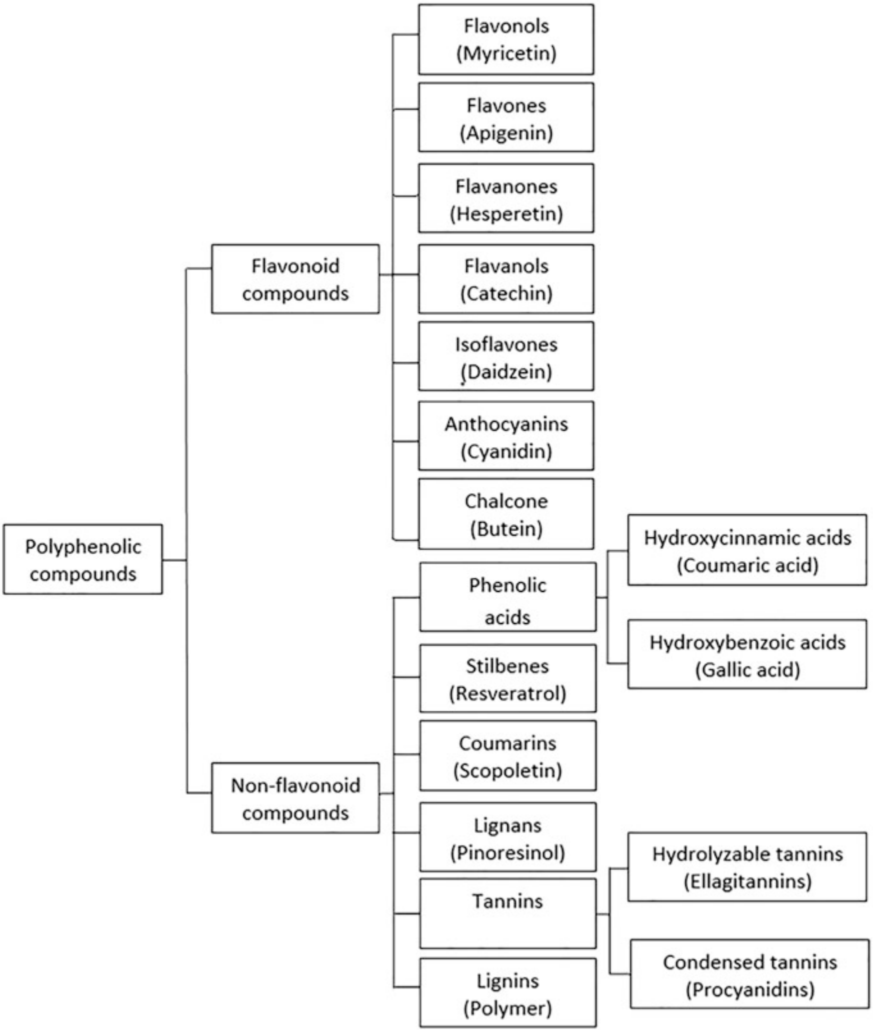

Fig. 1.3 Classification of naturally occurring polyphenolic compounds

common classification, these polyphenolics are divided into two main categories: one is flavonoids and other is non-flavonoid compounds. The flavonoid compounds are further divided into seven groups, viz., flavonols, flavones, flavanones, flavanols, isoflavones, anthocyanins, and chalcones, while coumarins, stilbenes, lignans, lignins, tannins (condensed and hydrolysable tannins), and phenolic acids (hydroxybenzoic and hydroxycinnamic acids) are the categories of non-flavonoid compounds (Fig. 1.3). Among these classes, phenolic acids, flavonoids, and tannins are the key ones, which have strong antioxidant potential (Ignat et al. 2011; Nunes et al. 2012; Dzialo et al. 2016 and references therein).

1.4.3 Flavonoids

Flavonoids are the category of SMs that have changeable phenolic structures and are widely found in plants. The first flavonoid was isolated in 1930 from oranges. Then, it was supposed to be a component of a new group of vitamins and was named as vitamin P. Afterward, it was established that the new component was a flavonoid (rutin). Till date, over 4000 flavonoids have been recognized (Kumar and Pandey 2013 and references therein).

Flavonoids have low molecular weight and occur as glycosides, aglycones, and methylated derivatives. The primary structure of flavonoids is aglycone (Fig. 1.4) and is composed of 15 carbon atoms with C6–C3–C6 arrangement. Basically, the structure is composed of two aromatic rings (A and B) joined through a three-carbon bridge, generally as a heterocyclic ring (denoted by letter C). Ring A is derived through malonate/acetate pathway, although the ring B is synthesized via shikimate pathway using phenylalanine. The key subclasses of flavonoids (flavones, flavanols, isoflavones, flavonols, flavanones, anthocyanins, and chalcones) resulted from the differences in the substitution pattern of the heterocyclic ring C. Out of all the classes of flavonoids, flavonols and flavones are broadly distributed and structurally most diverse. The substitutions on the rings A and B resulted in different constituents within all classes of flavonoids. The different substitutions might involve alkylation, acylation, oxygenation, sulfonation, and glycosylation, (Ignat et al. 2011; Kumar and Pandey 2013; Dzialo et al. 2016 and references therein).

The six-member heterocyclic ring C coupled with the benzene ring A is either α-pyrone (in case of flavanones and flavonols) or its dihydro derivative (in case of flavanones and flavanols). The position of benzene ring B at heterocyclic ring C segregates the flavonoid class into isoflavonoids (at carbon 3) and flavonoids (at carbon 2). Flavonoids usually have hydroxyl (OH) group at positions 5′, 4′, 3′, 7, 5, and 3. Among the glycoside derivative of flavonoids, the glycosidic bond is usually present at positions 7 or 3 and the linked carbohydrate moiety can be D-glucose, L-rhamnose, galactose, arabinose, or glucose rhamnose (Kumar and Pandey 2013 and references therein).

Flavonoids are generally found as glycosides (significantly as O-glycoside as compared to C-glycosides) dissolved in the vacuolar fluid of the plant cell. In various plant species, anthocyanins accumulate in the vesicles formed within the vacuole. Flavonoids are found very frequently in the dicotyledonous plants and are the only metabolites that have pharmacological potential. Flavonoids are mainly found in

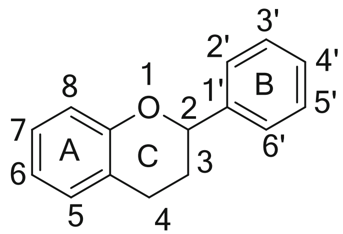

Fig. 1.4 Basic flavonoid aglycone structure

medicinal and aromatic plants, fruits, vegetables, legumes, seeds, certain grains, wine, coffee, cocoa, green tea, and herbal essences (Dzialo et al. 2016 and references therein).

Flavonoids have high redox potential, owing to which they act as singlet oxygen quenchers, hydrogen donors, and reducing agents. Apart from this, they also act as metal chelator. These properties of flavonoids make them powerful antioxidants. The antioxidant potential of flavonoids is varied according to the extent of structural conjugation, number/position of the hydroxyl functional groups, and the existence of electron-withdrawing and electron-donating functional groups in the ring structure. Flavonoids help to protect the plants from the injury produced by oxidative stress, pathogens, UV radiations, fungal infections, and herbivores. Flavonoids, when taken frequently by humans, help to reduce the chance of onset of a variety of degenerative diseases related to the heart, kidney, brain, etc. (Kumar and Pandey 2013; Dzialo et al. 2016 and references therein). Figure 1.5 represented the chemical structures of the key classes of flavonoids.

Flavonols Flavonols have the 3-hydroxyflavone backbone and extensively occur in plant kingdom. These are mainly found in various fruits and vegetables. Their content widely depends upon the different environmental conditions such as climate, storage, cooking, and growing conditions. Flavonols are the most active class of the flavonoid group and show a broad range of biological activities. Thus, the positive effects of fruit and vegetable diet against different diseases have been generally ascribed to flavonoids and more exclusively to flavonols. Many flavonols are commercialized as nutritional supplements either in pure form or as a mixture of flavonoids or extracts. Quercetin, myricetin, morin, rhamnetin, kaempferol, fisetin, and azaleatin are some naturally occurring flavonols, whereas rutin, robinin, astragalin, azalein, and myricitrin are some glycosides of flavonols that occur naturally (Ignat et al. 2011 and reference therein).

Flavones Flavones are naturally occurring group of oxygen heterocycles having 2-phenyl-1-benzopyran-4-one or 2-phenylchromen-4-one backbone (Marais et al. 2006). These are mainly found in cereals, fruits, vegetables, and herbs. Flavones have inimitable potential to modulate various enzyme systems, due to which they show a vast variety of biological activities such as antioxidant, anticancer, antibacterial, anti-allergic, antiviral, anti-osteoporotic, etc. Apigenin, luteolin, tangeritin, chrysin, wogonin, acacetin, and zapotin are the examples of some naturally occurring flavones (Singh et al. 2014 and references therein).

Flavanols Flavanols are also regarded as flavan-3-ols and have 2-phenyl-3,4-dihydro-2*H*-chromen-3-ol or 2-phenyl-3,4-dihydro-2*H*-benzopyran-3-ol skeleton (Marais et al. 2006). Flavanols are frequently present in polymerized form (oligomers (dimers to pentamers) and polymers – six or more units) within various plant-based food products. These are commonly found in fruits (mostly in peels and seeds), tea, cereals, and cocoa, but are absent in legumes and vegetables, with the exception of broad beans and lentils. Epicatechin, catechin, epigallocatechin,

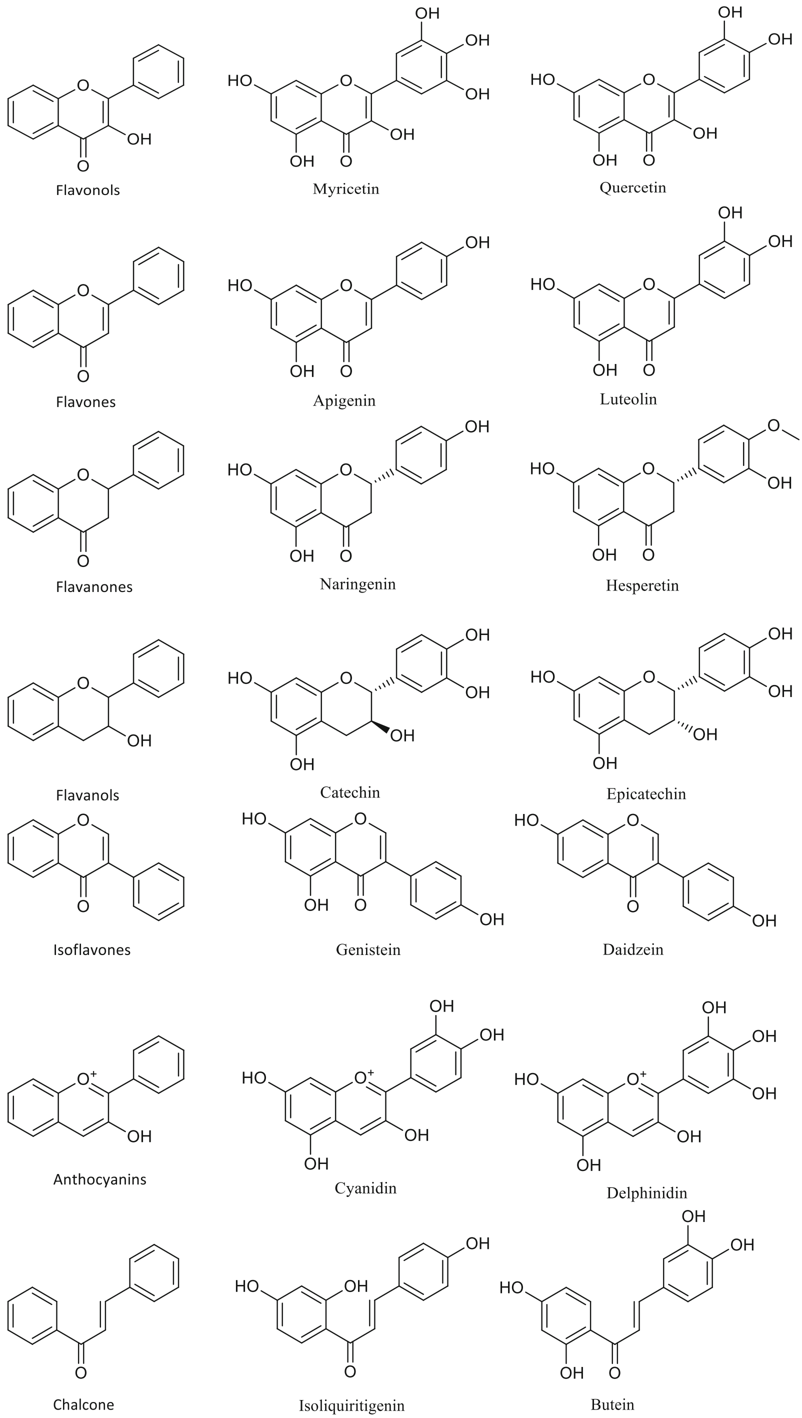

Fig. 1.5 The chemical structures of different key classes of flavonoids

gallocatechin, and their galloyl substituted derivatives, fisetinidol, mesquitol and guiboustinidol, are some examples of naturally occurring flavanols (Pascual-Teresa et al. 2010 and reference therein).

Flavanones Flavanones have a saturated three-carbon chain with a ketone functional group at C4. Flavanones differ from flavones by a C2-C3 single bond (Marais et al. 2006). These are extensively present in around 42 families of higher plants particularly in Leguminosae, Compositae, Lamiaceae, and Rutaceae. These are isolated from all the parts of plants such as seeds, fruits, flowers, cladode, leaves, bark, stem, peels, roots, tubers, rhizomes, etc. Flavanones are frequently glycosylated by a variety of disaccharide at position C7. The citrus fruit contains high concentration of flavanones, and their concentration is higher in peel than the fleshy part of citrus fruit. Besides citrus plants, these also occurred in certain aromatic plants. Till date, approximately 350 flavanone aglycones and 100 glycosides of flavanone are recognized in nature. Naringenin, hesperetin, eriodictyol, butin, sakuranetin, and sterubin are some major flavanone aglycones, whereas hesperidin, naringin, poncirin, and sakuranin are some key flavanone glycosides obtained from a variety of higher plant species (Ignat et al. 2011; Khan and Zill-E-Huma 2014 and reference therein).

Isoflavones Isoflavones have an aromatic ring at C3position as compared to their corresponding flavones, which have an aromatic ring at C2 position. Isoflavones have also structural resemblance to estrogens as they hold hydroxyl groups at positions C7 and C4 like estradiol (Klejdus et al. 2007). These are present in over 300 plant species belonging to 59 families. Plants belonging to family Leguminosae and subfamily Papilionideae are the major source of isoflavones in the nature. These are mainly found in the seeds and roots. Isoflavones are also produced by some bacteria and fungi. Isoflavones play significant role in the process of symbiosis among rhizobium-legume and also play key role in defense mechanisms against plant pathogens. Among the members of family Leguminosae, soybeans are the foremost sources of isoflavones in nature. Isoflavones are present as conjugates of glucose in the plants. These gluco-conjugates are biologically inactive and are hydrolyzed to their active forms (aglycones) by the action of bacteria residing in the human intestine. Isoflavones are well acknowledged for their health-promoting effects like estrogenic or antiestrogenic activity, anti-inflammatory effect, antioxidant activity, antiproliferation of cancer cells, prevention of osteoporosis, reduction in cardiovascular disease, regulation of the immune system, alteration in cellular signaling, and alleviation of postmenopausal syndrome. Daidzein, genistein, biochanin A, glycitein, luteone, wighteone, and formononetin are the examples of some naturally occurring isoflavone aglycones. Out of these, daidzein and genistein are the most significant biologically active isoflavones in humans (Reinli and Block 1996; Ignat et al. 2011; Preedy 2013 and references therein).

Anthocyanins Anthocyanins are polymethoxy and polyhydroxy derivatives of 2-phenylbenzopyrylium, which form the core of anthocyanins known as anthocyanidin. This anthocyanidin core is also linked to many glycosidic moieties (glucose, fructose, galactose, rhamnose, arabinose, and xylose) at the positions C7, C5, or C3. The anthocyanidin core consists of an aromatic ring A fused with heterocyclic ring C that contains oxygen, which further united to a third aromatic ring B by a C-C single bond (Konczak and Zhang 2004; Smeriglio et al. 2014). Anthocyanins are water-soluble vacuolar pigments with blue, red, or purple appearance at different pH. These are synthesized by the phenylpropanoid pathway and are present in all plant parts (seeds, fruits, flowers, leaves, cladode, stems, bark, and roots. The isolated anthocyanins are very unstable in nature, and their stability depends upon various factors such as chemical structure, light, oxygen, pH, solvents, storage temperature, concentration, and the presence of metallic ions and enzymes (Ignat et al. 2011 and references therein).

Anthocyanins play a significant role in attracting animals for seed dispersal and pollination and in absorbing UV radiation from light, thereby protecting the plants from damage caused by UV radiations (Castañeda-Ovando et al. 2009). Anthocyanins are well recognized for their antioxidant potential. Apart from this, they also show a wide range of biological activities from cytoprotective, anti-inflammatory, and anti-obesity to neuroprotective, antimicrobial, and lipidomic potential (Smeriglio et al. 2016). Pelargonidin, cyanidin, peonidin, delphinidin, petunidin, malvidin, aurantidin, europinidin, and rosinidin are the anthocyanidins that occur most commonly in plants. The glycoside derivatives of cyanidin, pelargonidin, and delphinidin are the most frequent pigments found in nature, which form 80%, 69%, and 50% of leaves, fruits, and flower's total pigment content, respectively (Smeriglio et al. 2016 and references therein).

Chalcones Chalcones are the naturally occurring compounds made up of 1,3-diphenylprop-2-en-1-one backbone that has two aromatic rings linked through a α, β-unsaturated three-carbon carbonyl system. These are present in large amount in edible plants and act as metabolic pioneers for the formation of innumerable flavonoids and isoflavonoids. The rich sources of chalcones are hops, citrus fruits, vegetables (tomatoes, shallot, potatoes, etc.), spices (licorice, cardamom), bean sprouts, and beer. Plants rich in chalcones are employed in various traditional herbal medicine systems (Yerragunta et al. 2013; Chavan et al. 2016). Presently, chalcones are significantly attracting the attention of the scientific world due to their wide range of therapeutic potential, viz., antioxidative, analgesic, antibacterial, immunomodulatory, antimalarial, anti-inflammatory, antiviral, antileishmanial, antiplatelet, antihyperglycemic, anticancer, cytotoxic, and inhibition of aldose reductase and tyrosinase activities (Sankappa et al. 2015). Butein, isoliquiritigenin, derricin, lonchocarpin, heliannone A, kukulcanin B, lichochalcone A, morachalcone, and dorsmannin are the examples of some naturally occurring chalcones (Yerragunta et al. 2013; Singh et al. 2014; Chavan et al. 2016 and references therein).

1.4.4 Non-flavonoid Polyphenolics

The naturally occurring non-flavonoid polyphenolic constituents are primarily classified into stilbenes, coumarins, tannins, lignans, lignins, and phenolic acids (hydroxycinnamic and hydroxybenzoic acids). Among these, phenolic acid, coumarins, and tannins are the significant ones. Figure 1.6 represents the examples of a few compounds of various classes of non-flavonoid polyphenolics (Rentzsch et al. 2009).

Phenolic Acids These are broadly distributed in plant kingdom and comprise nearly one-third of the total dietetic phenols. These occur both in free and bound state in the plants, and in the bound state these are linked with various other natural molecules (flavonoids, sterols, fatty acids, and cell wall polymers) via ester, acetal, or ether bonds. Phenolic acids are mostly found in coffee, tea, tobacco leaves, wine, cinnamon, blueberries, blackberries, cherries, fruits (kiwis, apples, plums, grapes, etc.), vegetables (onion, potatoes, cabbage, radish, spinach, broccoli, etc.), bean, olive oil, and grains. Phenolic acids comprise of two subcategories, the hydroxycinnamic (C6-C3) and hydroxybenzoic (C6-C1) acids (Fig. 1.6) (Bravo 1998). The hydroxybenzoic acids are generally present in low concentration in edible plants, with some exceptions like red fruits, black radish, and onions which have high content of hydroxybenzoic acids. Protocatechuic, gallic, vanillic, syringic, and p-hydroxybenzoic acids are some of the key hydroxybenzoic acids commonly found in plants. The hydroxybenzoic acids of plant origin mostly occur in their glycosidic form. The hydroxycinnamic acids and their derivatives are the most prevalent phenolic acids occurring in plants. Caffeic, ferulic, chlorogenic, sinapic, o-coumaric, m-coumaric, and p-coumaric acids are the major hydroxycinnamic acids found most frequently in plants (Ignat et al. 2011; Kumar et al. 2015 and references therein).

The phenolic acids are produced in the plant species as the protective measure against UV light, insects, bacteria, and viruses. Further, some plant species also synthesized the phenolic compounds in order to retard the growth of other plant contestants (allelopathy). Phenolic acids have high redox potential due to which they show high antioxidant potential. Apart from this, phenolic acids also show antitumor, antimicrobial, cytotoxic, chemopreventive, apoptotic, and neuroprotective activities (Saibabu et al. 2015 and references therein).

Coumarins Coumarins represent one of the key classes of non-flavonoid polyphenolics having 2H-1-benzopyran-2-one framework found naturally in plants. In coumarin benzene ring is fused with α-pyrone ring due to which these are also known as benzopyrones. Coumarins are further subdivided into different groups ranging from simple coumarins to polycyclic coumarins like furocoumarins and pyranocoumarins. Coumarins are mainly present in the integument of flowers, fruits, seeds, leaves, stems, and roots, but their higher concentration is usually found in flowers and fruits. Till date about 1300 different coumarins have been isolated from

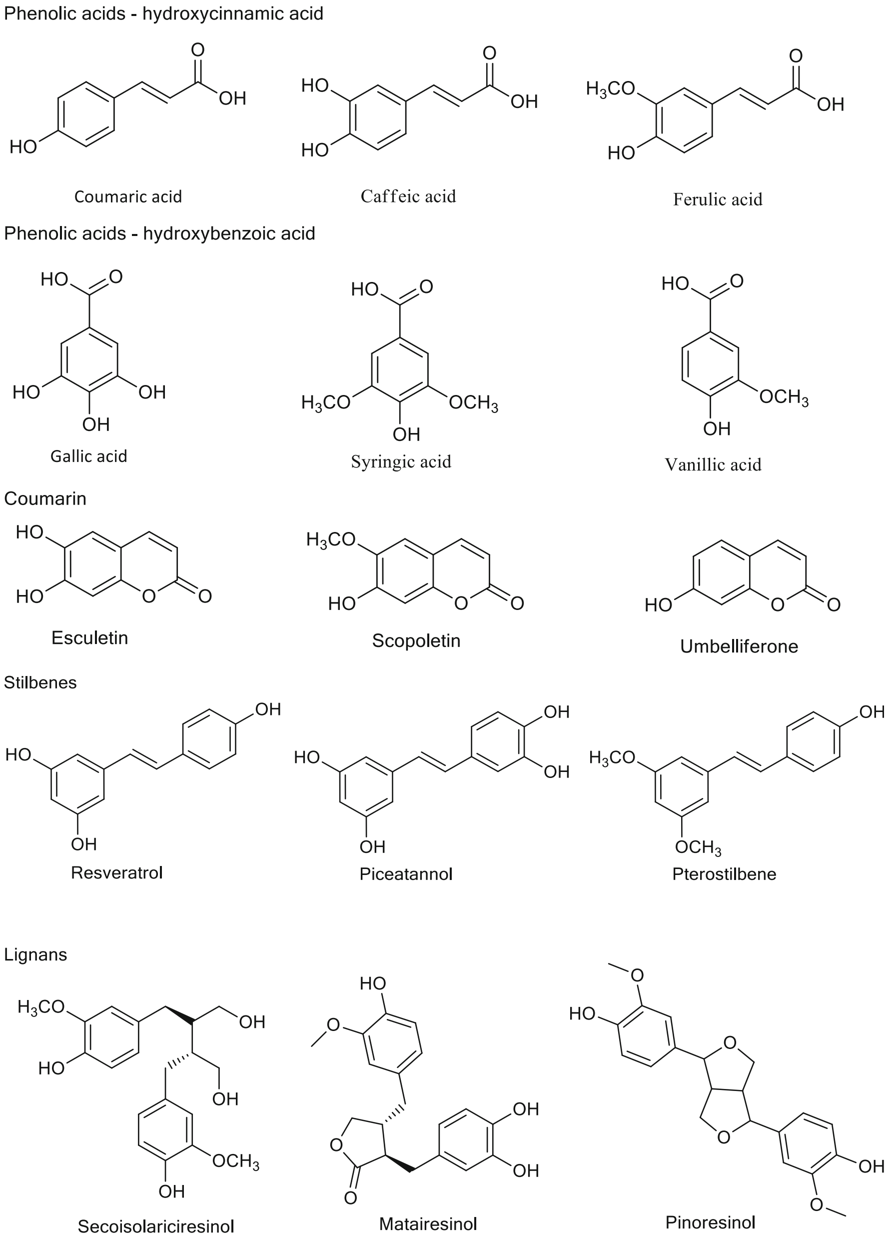

Fig. 1.6 Chemical structures of a few compounds/precursors of various classes of non-flavonoid polyphenolics

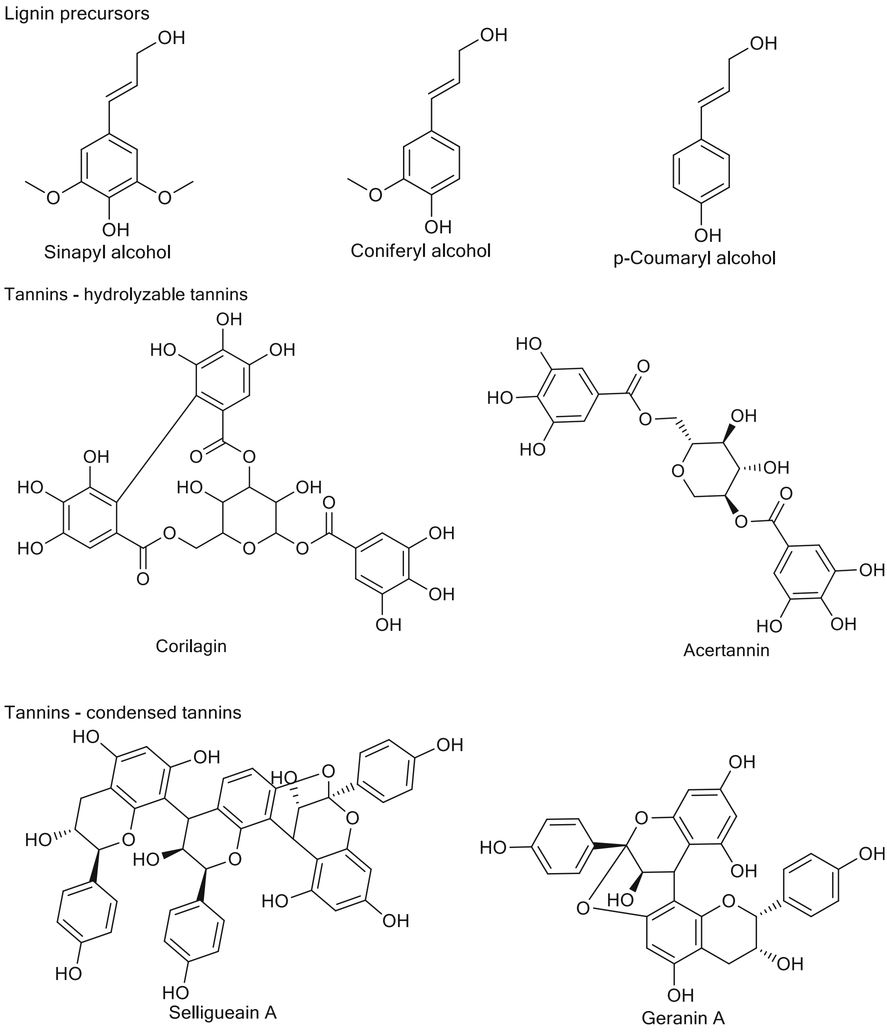

Fig. 1.6 (continued)

more than 100 plant species belonging to over 40 different families. Vegetables, fruits, seeds, nuts, coffee, tea, and wine are the rich sources of coumarins. Coumarins are well acknowledged for their pharmacological activities, viz., antioxidant, antihypertensive, anti-inflammatory, anticonvulsant, anticancer, anticoagulant, antitubercular, antiadipogenic, antihyperglycemic, antibacterial, antifungal, and antiviral. Esculetin, scopoletin, umbelliferone, ammoresinol, ostruthin, fraxidin, osthole, and novobiocin are the examples of some naturally occurring simple coumarins (Venugopala et al. 2013; Matos et al. 2015 and references therein).

Stilbenes Stilbenes are composed of two phenyl rings linked through a methylene bridge of two carbons. Stilbenes are found in stereoisomer form, and the stilbenes of natural origin exist in the trans form. Naturally, these are found both in free and glycosylated forms as polymeric, trimeric, and dimeric stilbenes. Stilbenes are present in very low concentration in the human diet. These are produced in plants as a response to a variety of stress conditions and infections caused by pathogens. Currently, stilbenes are isolated from over 70 plant species (berries, grapes, peanuts, etc.) (Bavaresco 2003). Resveratrol, pterostilbene, and piceatannol are the common naturally occurring stilbenes, which are well known for their antioxidant, anticancer, anti-inflammatory, antifungal, and phytoalexin potential (Ignat et al. 2011; Kumar et al. 2015 and references therein).

Lignans Naturally occurring lignans are derived from two phenylpropane (C6-C3) units by oxidative dimerization, and the final product is linked by two specific carbons (C2-C2′). Further reactions of lignans (cyclization, isomerization, etc.) lead to a broad range of structures. Lignans are mostly found in their free form, whereas their bonded forms (glycoside derivatives) occur only in a small amount. The naturally occurring lignans and their synthetic derivatives show potential applications in cancer chemotherapy (skin, breast, colon, and lung cancer) (Saleem et al. 2005). Many lignans, like secoisolariciresinol and matairesinol, are considered as phytoestrogens and are processed through the intestinal microflora into enterolactone and enterodiol. Thus, like isoflavones, lignans have both antiestrogenic and estrogenic activities. Apart from this, lignans also show various pharmacological activities such as antioxidant, antiviral, anticancer, anti-inflammatory, hepatoprotective, and immunosuppressive. Lignans are mostly found in the form of complicated biopolymers, due to which they lack a distinct primary carbon base, and every particular lignan has their own unique chemical structure. The key sources of lignans are the seeds like linseed, flax, cereals, legumes, grains, fruits, certain vegetables, and algae. Secoisolariciresinol, matairesinol, pinoresinol, and podophyllotoxin are some naturally occurring lignans in the plants (Ignat et al. 2011; Kumar et al. 2015 and references therein).

Tannins Generally, these have high molecular weight and are widely distributed in plants. In plants tannins mostly occur in two forms, hydrolyzable tannins (formed by self-polymerization of phenolic acids or with sugar) and condensed tannins (combination of flavonoids). Mostly the hydrolyzable tannins are derived from gallic acid. The gallic acid gets esterified to generate a core polyol followed by further esterification of galloyl groups which oxidatively cross-linked to produce further complex hydrolyzable tannins (Hagerman 2002). Condensed tannins also known as proanthocyanidins are the polymeric flavonoids. In spite of well-established or understood biosynthetic pathways of flavonoid synthesis, the steps leading to condensation or polymerization of flavonoids to produce condensed tannins are yet to be elucidated. The frequently examined condensed tannins are synthesized from flavan-3-ols like (+)-catechin and (−)-epicatechin. In biological systems, the tannins act as potential protein precipitating agents, metal ion chelators, and biological antioxidants. Further, like other polyphenols, tannins also show various biological activities like antimicrobial, anticarcinogenic, anti-inflammatory, antioxidant, and cardiovascular system-protective. Tannins showed strong antioxidant potential, which is mainly attributed to their potential to scavenge free radical, to form chelate with transition metals, and to inhibit lipid peroxidation and activity of pro-oxidative enzymes. Tannins are widely found in both angiosperms and gymnosperms. These are known to occur in around 180 and 44 families of dicotyledons and monocotyledons, respectively. Hydrolyzable tannins are frequently found in leaf, cladode, bud, fruits, seed, root, and stem, whereas condensed tannins are mostly found in wood and bark of the plants (Mole 1993; Chung et al. 1998; Smeriglio et al. 2017 and references therein).

Lignin Lignin is a complex organic polymer comprised of different phenylpropane units linked together. These phenylpropane units originated from three aromatic alcohol precursors (monolignols) sinapyl, coniferyl, and p-coumaryl alcohols. Lig nin is the key component present in the structural materials of support tissues (cell walls, wood, and bark) of vascular plants and some algae. Lignin is the second largest polymer on the planet after cellulose obtained from the biomass. The woody plants contain up to 15–25% of lignin of their dry weight. In woody plants, lignin provides mechanical support for binding plant fibers together, structure and strength to the cell walls, protection against biochemical stresses, and help in the flow of plant fluid (water) and nutrients. Lignins and their derivatives also show many pharmacological activities such as antiviral, antitumor, antidiabetics, immunomodulator, and obesity control (Laurichesse and Averous 2014; Vinardell and Mitjans 2017 and references therein).

1.5 Essential Oils as Natural Antioxidants

Essential oils are the natural, aromatic, oily, volatile, transparent, rarely colored liquids with strong odor isolated from different plant parts. Essential oils are complex mixtures of volatile terpenes and their oxygenated derivatives, hydrocarbons, aromatic compounds, simple alcohol, ketones, and ether. These are widely used as flavoring agents in food and pharmaceutical industries. Till date, about 3000 essential oils are isolated, out of which only 300 are commercially significant particularly in food, pharmaceutical, agronomic, cosmetic, sanitary, and perfume industries (Silva et al. 2003; Bakkali et al. 2008; Amorati et al. 2013 and references therein).

Essential oil plays a vital role in plants, where they act as insecticides, antibacterial, antifungal, and antiviral agents. They also protect plants against the action of different herbivores. Sometimes, they also help to attract the various insects, which further help to spread the pollen or to repel harmful insects. Essential oils are synthesized by all the plant parts, viz., buds, leaves, flowers, cladode, fruits, stems, roots, bark, and seeds. In the plants, these are stored in epidermal cells,

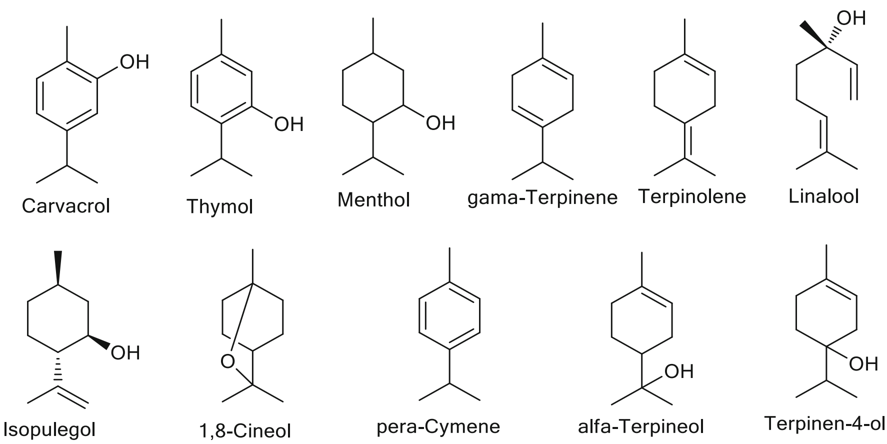

Fig. 1.7 Different volatile monoterpenes that have antioxidant potential

secretory cells, glandular trichomes, channels, and cavities. (Bakkali et al. 2008; Nunes et al. 2012 and references therein).

Terpenoids are structurally diverse group of compounds derived from multiples of n isoprene units (C5). These are classified as follows: hemiterpenes (C5), only one isoprene moiety; monoterpenes (C10), two isoprene moieties; sesquiterpenes (C15), three isoprene moieties; diterpenes (C20), four isoprene moieties; sesterpenes (C25), five isoprene moieties; triterpenes (C30), six isoprene moieties; and tetraterpenes (C40) – eight isoprene moieties. Mono-, sesqui-, and diterpenes and their oxygenated derivative are basic components of the essential oils. Essential oils are well recognized for their pharmacological potential such as sedative, expectorant, diuretic, antispasmodic, antiviral, anti-inflammatory, antipyretics, insecticidal, antimicrobial, fungicidal, etc. (Bakkali et al. 2008; Amorati et al. 2013 and references therein).

Essential oils also act as natural antioxidants and this is one emerging field with growing interest, particularly in cosmetics, food science, aroma science, and complementary medicine. Antioxidant potential plays a central role in a variety of essential oil's biological activity that is described through the contribution of oxidative stress. Components of essential oils particularly terpenes and phenols help to delay or stop the oxidative reaction going on in the organic matter (Amorati and Foti 2012). Further, the phenolic content of essential oil is very limited, due to which their antioxidant potential of essential oils is mainly attributed to the existence of mono-, sesqui-, and diterpenes and their oxygenated derivatives. Carvacrol, thymol, menthol, ϒ-terpinene, linalool, terpinolene, 1,8-cineole, isopulegol, ρ-cymene, α-terpineol, and terpinen-4-ol are the different monoterpenes, which show antioxidant activity (Fig. 1.7) (Nunes et al. 2012, Amorati et al. 2013 and references therein). Some volatile phenylpropanoids (viz., eugenol, safrole, myristicin, cinnamaldehyde, guaiacol, coniferil alcohol, syringaldehyde, umbelliferone, etc.) and alkaloids (piperine) present in various essential oils obtained from some

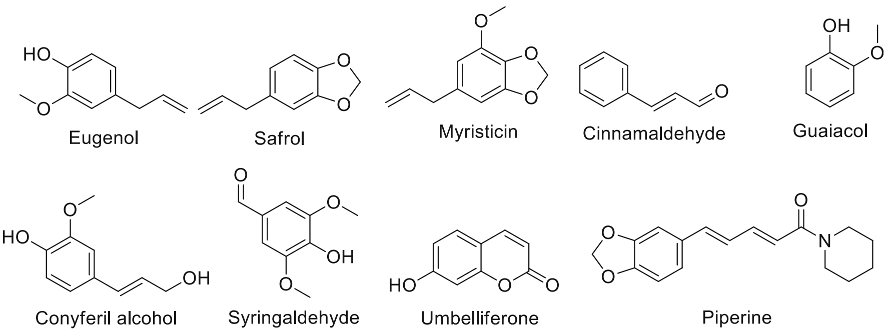

Fig. 1.8 Different volatile phenylpropanoids and alkaloid that have antioxidant potential

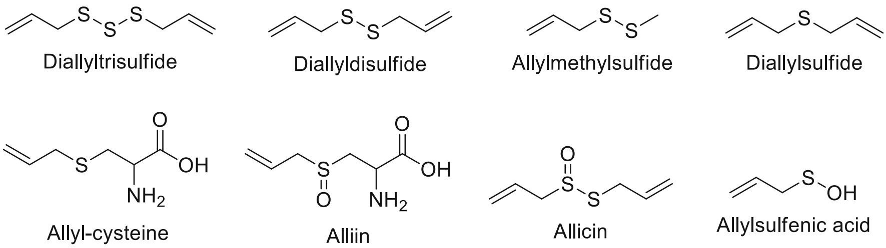

Fig. 1.9 Different volatile sulfur-containing natural antioxidants present in the essential oil of *Allium* species

particular plants also act as natural antioxidants (Fig. 1.8) (Brewer 2011; Amorati and Foti 2012; Amorati et al. 2013 and references therein).

1.6 Sulfur-Containing Natural Antioxidants

The essential oils/extracts obtained from various species of genus *Allium* (scallions *Allium fistulosum*, garlic *Allium sativum*, leeks *Allium ampeloprasum*, onions *Allium cepa*, shallots *Allium cepa* var. aggregatum, etc.) were rich source of different sulfur-containing compounds mainly volatile in nature. The composition of sulfur-containing compounds in different extracts and essential oils mainly depends upon the methods of isolation. The essential oil isolated from garlic by hydro and steam distillation mainly contained diallyl disulfide (25%) and diallyl trisulfide (50%) (Banerjee et al. 2003; Brewer 2011; Amorati et al. 2013 and references therein). It also contained diallyl sulfide, methyl allyl disulfide, and methyl allyl trisulfide in small amount. All these sulfur-containing compounds act as natural antioxidant. Some compounds such as alliin, allicin, and allyl sulfenic acid are not present in *Allium* species but are formed during their processing (upon homogenation) and are also known to possess high antioxidant potential (Brewer 2011; Amorati et al. 2013 and references therein). Figure 1.9 represents various sulfur-containing natural antioxidants present in different *Allium* species.

1.7 Miscellaneous Natural Antioxidants

Apart from above key classes of SMs which act as natural antioxidant, there also exists another class of SMs which are also known for their antioxidant potential such as alkaloids, carotenoids, and vitamins. Alkaloids mainly having tetrahydro-beta-carboline, piperidine, benzylisoquinoline, and boldine moieties in their structure also act as potent source of natural antioxidant (Fig. 1.10). These alkaloids are mainly present in spices, plants, fruits, and different food products (Cassels et al. 1995; Herraiz and Galisteo 2002; Brewer 2011; Muthna et al. 2013). Carotenoids (viz., beta-carotene, lycopene, zeaxanthin, etc., Fig. 1.10) represent another key class of natural antioxidants and are mainly obtained from vegetables and fruits such as carrots, potatoes, apricots, and papayas (Anwar et al. 2018). Further, various vitamins (vitamins A, C, and E, Fig. 1.10), minerals (Se selenium, Mg magnesium, Zn zinc, Cu copper, etc.), proteins, and peptides of plant origin also act as significant source of natural antioxidant (Sarmadi and Ismail 2010; Anwar et al. 2018)

1.8 Extraction Methods Used for Isolation of Natural Antioxidants

Natural antioxidants belong to various classes of SMs, and these can be obtained from plants by using both conventional and modern extraction methods. Modern extraction methods are more economical and eco-friendly in nature as compared to the conventional extraction methods, and due to this the latter ones are more and more often being replaced by the former ones (Pisoschi et al. 2016). The percentage extractive yield largely depends upon the extraction method and solvent used. Further, it also depends upon the time of extraction, feed-to-solvent ratio, temperature, and repeated extraction cycle number. Solubility of SMs largely depends upon extraction temperature and time. Higher extraction temperature significantly increases the solubility and mass transfer of SMs and simultaneously decreases the surface tension/viscosity of extraction solvents that consequently enhance the extraction rate of SMs (Brunner 2005; Mojzer et al. 2016). In order to remove unwanted compounds such as fats and fatty esters, waxes, chlorophylls, and other long-chain hydrocarbons, the plant material is first extracted with nonpolar solvents such as pet ether, cyclohexane, hexane, benzene, dichloromethane, chloroform, etc. (Mojzer et al. 2016).

Natural antioxidants can be extracted from dried, frozen, and fresh plant samples like roots, tuber, rhizomes, stems, peel, bark, leaves, cladode, flowers, and fruits. Prior to extraction, the plant material should be pre-treated by grinding, milling, homogenizing, and drying. The choice of drying method significantly influences the content of natural antioxidants. Mostly shade air-drying and freeze-drying methods

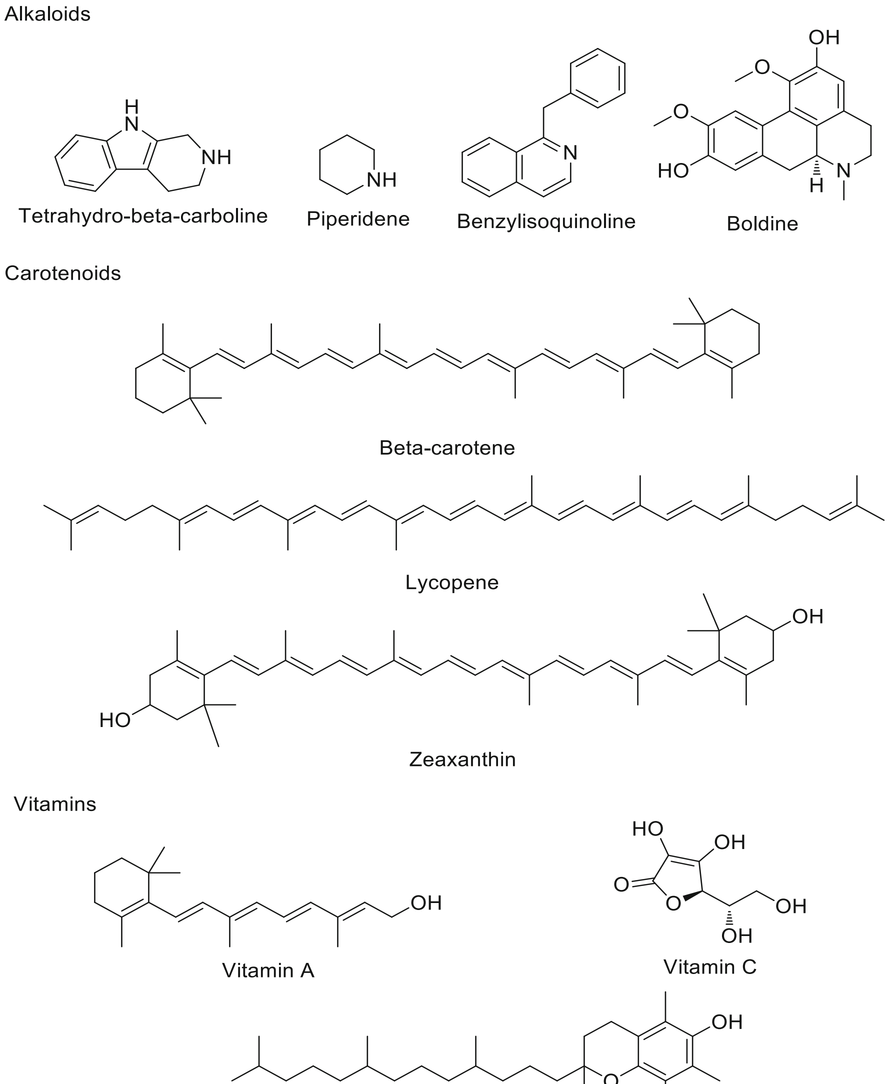

Fig. 1.10 Miscellaneous classes of natural antioxidants obtained from plants

are used for drying of plant material prior to the isolation of natural antioxidants (Abascal et al. 2005; Ajila et al. 2011; Mojzer et al. 2016).

Regardless of various disadvantages, conventional liquid-solid and liquid-liquid isolation methods are still frequently used extraction techniques. These conventional techniques have been widely used from past many years mainly due to their wide-ranging applicability, efficiency, and ease of use (Qiu et al. 2010; Mojzer et al.

2016). Soxhlet, maceration, infusion, percolation, decoction, cold pressing, etc. are the various conventional extraction methods used to isolate SMs/natural antioxidants (Azmir et al. 2013; Pisoschi et al. 2016). Out of these conventional extraction procedures, maceration and Soxhlet are most widely used for the isolation of natural antioxidants owing to their high efficiency and wide-ranging applicability as compared to other conventional methods (Mojzer et al. 2016; Sharma and Cannoo 2017). For the isolation of volatile natural antioxidants, the most widely used extraction techniques are hydro-distillation and steam distillation.

Nowadays, several modern extraction methods like ultrasound-assisted extraction, pressurized liquid extraction, ultrasound-microwave-assisted extraction, microwave-assisted extraction, negative pressure cavitation extraction, supercritical fluid extraction, and matrix solid-phase dispersion, etc. are also employed for the isolation of natural antioxidants. These modern methods use less solvent volume, reduce the extraction time, and improve the percentage extractive yield. These procedures are more sensitive, selective, and reproducible in nature as compared to conventional techniques. Among the modern extraction methods, supercritical fluid extraction, microwave-assisted extraction, and ultrasound-assisted extraction are usually used extraction approaches for the isolation of natural antioxidants (Gupta et al. 2012; Brusottia et al. 2014; Pisoschi et al. 2016; Cikos et al. 2018).

1.9 Extraction Solvents Used for Isolation of Natural Antioxidants

A variety of nonpolar, medium polar, and polar solvents (hexane, dichloromethane, chloroform, ether, ethyl acetate, acetone, butanol, ethanol, methanol, water, and combination of polar solvents) has been used for the isolation of natural antioxidants by various researchers all over the world. Among these solvents, ethanol, methanol, and water are most frequently used solvents. These solvents have high dialectic constant and good polarity. Owing to this, these are used most favorably to extract polar natural antioxidants like phenolic acids, flavonoids, tannins, etc. according to the fact "like dissolves like" (Alam et al. 2013; Sharma and Cannoo 2016a, b; Patial et al. 2019). As the ethanol is organic and nontoxic in nature, it is largely used for the extraction of natural antioxidants as compared to methanol which is toxic in nature. Further, the removal of water from the extract after extraction is a big problem due to its high boiling points and it needs some special methods of freeze-drying. On the other hand, the nonpolar and medium polar solvents have been used only in some specific cases. In addition, their availability also confines their use for the isolation of natural antioxidants (Alam et al. 2013; Sharma and Cannoo 2016a, b; Patial et al. 2019).

1.10 Methods of Evaluation for Antioxidant Potential of Natural Antioxidants

The different naturally occurring antioxidants have diverse mechanisms of action. These may serve as decomposers of various peroxides, terminators of chain initiation reaction, hydrogen abstractors, binders in transition metal ion catalysts, and scavengers of various free radicals. As a result, it is very difficult to assess an absolute antioxidant potential profile of any NOAs/plant extract by a single antioxidant assay (Niki 2011, 2016; Sharma and Cannoo 2016a, b). Thus, in order to have an absolute antioxidant potential profile of plant extract, it's better to evaluate antioxidant potential by employing a number of antioxidant assays (Sharma and Cannoo 2016a, b; Sharma and Cannoo 2017).

Currently more than 35 types of antioxidant assays are in use for the assessment of antioxidant potential of various plant extracts, essential oils, and different foodstuff. Out of these 30 assays, various assays are used in one and other form with some modifications. These antioxidant assays can be broadly classified into two groups in vitro and in vivo assays (Fig. 1.11) (Huang et al. 2005; Alam et al. 2013; Pisoschi et al. 2016).

1.10.1 In Vitro Assay

Presently more than 25 types of in vitro methods are in use. Usually in vitro antioxidant methods are straightforward and relatively easy to perform as compared to in vivo methods. These in vitro methods can be further classified in different groups depending upon their mode of action such as single electron transfer (SET) methods, hydrogen atom transfer (HAT) methods, mixed methods (have both HAT and SET mechanism), chelation methods, lipid oxidation methods, and miscellaneous methods (Fig. 1.11). Table 1.2 presents the division of different in vitro

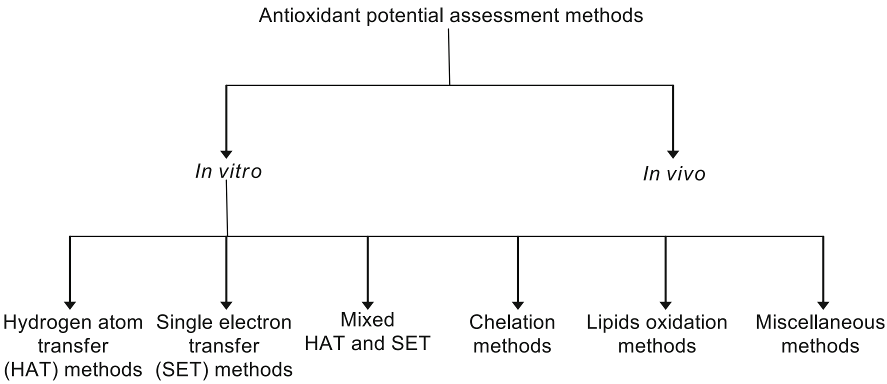

Fig. 1.11 Classification of different antioxidant assessment methods

Table 1.2 Various in vitro assays commonly employed to assess the antioxidant activity (Huang et al. 2005; Prior et al. 2005; Alam et al. 2013; Pisoschi et al. 2016)

Sr. no.	Underlying mechanism	Antioxidant assay
1.	Hydrogen atom transfer (HAT) methods	Total radical trapping antioxidant parameter (TRAP) assay
		Oxygen radical absorbance capacity (ORAC) assay
		Beta-carotene/crocin bleaching assay
		Inhibited oxygen uptake (IOU) assay
		Inhibition of induced low-density lipoprotein peroxidation assay
2.	Single electron transfer (SET) methods	N,N-Dimethyl-p-phenylenediamine (DMPD) assay
		Ferric reducing antioxidant power (FRAP) assay
		Cupric reducing antioxidant capacity (CUPRAC) assay
		Potassium ferricyanide reducing power (PFRAP) assay
		Total phenolic content assay by Folin-Ciocalteu assay
		Total antioxidant capacity (TAC)/ phosphomolybdenum assay
3.	Mixed methods (have both HAT and SET mechanism)	2,2-Diphenyl-1-picrylhydrazyl (DPPH) scavenging assay
		2,2′-Azinobis-(3-ethyl-benzothiazoline)-6-sulfonic acid (ABTS) assay Trolox equivalent antioxidant capacity (TEAC)
4.	Chelation methods	Tetramethylmurexide (TMM) assay
		Ferrozine/metal chelating assay
5.	Lipid oxidation methods	Thiobarbituric acid (TBA) assay
		Anisidine assay
		Conjugated diene assay
		Peroxide value assessment assay
6.	Miscellaneous methods	Hydrogen peroxide scavenging (H_2O_2) assay
		Peroxynitrite (ONOO) radical scavenging assay
		Nitric oxide (NO) scavenging assay
		Hydroxyl radical scavenging assay
		Hydroxyl radical averting capacity (HORAC) assay
		Superoxide radical scavenging (SOD) assay
		Xanthine oxidase assay

antioxidant assays into different groups depending upon the mechanism of action (Prior et al. 2005; Alam et al. 2013; Pisoschi et al. 2016).

1.10.2 In Vivo Assay

All the in vivo methods are performed usually by the administration of natural antioxidant containing samples to the testing animals such as mice, rats, and rabbits at a definite schedule dose as illustrated in the respective method. After a definite span of time, the testing animals are generally sacrificed, and tissues, blood, and blood serum are used for the method. Due to this, in vivo methods are more difficult to perform as compared to in vitro methods. Presently about ten types of in vivo methods are in use, viz., ferric reducing ability of plasma, glutathione peroxidase (GSHPx) estimation, reduced glutathione (GSH) estimation, glutathione reductase (GR) assay, glutathione-S-transferase (GSt), low-density lipoprotein (LDL) assay, catalase (CAT) method, superoxide dismutase (SOD) method, lipid peroxidation (LPO) assay, and gamma-glutamyl transpeptidase activity (GGT) assay (Alam et al. 2013).

Among the various in vitro assays, the seven most frequently used methods in order of increasing frequency are potassium ferricyanide reducing power (PFRAP) < nitric oxide (NO) scavenging < metal chelating < beta-carotene < superoxide radical scavenging (SOD) < hydroxyl radical scavenging assay < DPPH scavenging assay. The DPPH assay is the most frequently used among the all assay as it is the simplest, easy to perform, and takes less time for completion. Whereas in case of various in vivo assays, the six most frequently used methods (to assess the antioxidant potential of natural antioxidant rich samples) in order of increasing frequency are glutathione reductase (GR) < reduced glutathione (GSH) < glutathione peroxidase (GSHPx) < catalase (CAT) < superoxide dismutase (SOD) < lipid peroxidation (LPO) assay (Alam et al. 2013).

1.11 Conclusion

Nowadays, the scientific knowledge and awareness about naturally occurring antioxidants, their methods of isolation, and their antioxidant potential assessment techniques (in vivo and in vitro) have been increasing significantly. This chapter provides significant information regarding oxidative stress, free radicals (FRs), and reactive oxygen/nitrogen species, their biological roles, and various routes of their production. The chapter also provides brief knowledge about the importance of various classes of natural antioxidants and their mode of action along with the accessibility of different extraction methods/solvents to from their natural resources. At the end, the chapter presents the detailed information about the various in vitro and in vivo methods currently used for the evaluation of antioxidant potential of plant extracts, essential oils, vegetables, fruits, and other dietary sources. Presently, in vitro methods of antioxidant potential evaluation have become important tools for the investigation of new bioactive SMs (natural antioxidants). These tests assist to authenticate the importance of essential oils, plant extracts, vegetables, fruits, and other dietary products as effective antioxidant by verifying the presence of natural antioxidants in them. These natural antioxidants aid to fight against the injuries caused by oxidative stress conditions. Nevertheless, the increasing demand for new bioactive SMs (natural antioxidants) from natural sources boosts the invariable search for new and novel methods to extract, isolate, and evaluate (biological potential) new potent SMs, which never ends. The knowledge provided in the present chapter will be helpful to the beginner in this field.

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Cherry

2

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Abstract

The antioxidant characteristics associated with the cherry fruit components that mainly involve polyphenolic compounds like flavonoids and anthocyanins have resulted in an increase in its global production and consumption. This chapter provides a comprehensive summary related to cherry fruit, cherry fruit juices, seeds, and cherry fruit by-products and the health benefits thereof. The bioactive compounds in cherry and its by-products provide immense biological properties which have the potential preventive health benefits with respect to oxidative stress, cancer, cardiovascular diseases, diabetes, inflammatory disorders, and arthritis.

Keywords

Cherry · Flavonoids · Anthocyanins · Health benefits · Cardiovascular diseases

Botanical Name and Common Name

Prunus avium L.	Sweet cherry
Prunus cerasus L.	Tart cherry

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2.1 Introduction

2.1.1 History

The archaeological evidences reveal cherry stones dating back to 5000–4000 BC, which reveal the cherries to be one of the oldest fruits used by humans for consumption. Among the archaeological evidences of cherry, the fruit pits were the first to be found in European caves (Janick 2011). Theophrastus was the first to name and describe sweet cherry around 300 BCE in the form of a large tree bearing red and round fruits. The tree was named Kerasos after the town of Kerasum. According to the archaeological excavations in Germany, the fruit was a part of the dietary component by the Roman era (Janick 2011). The ancient Greeks domesticated and introduced the fruit from the north-east Turkey to Europe (England and Italy). The Roman cherry cultivars including ‘Junian’ related to the French ‘Guigne’ and the ancient cultivar ‘Lusitanina’ related to the modern cultivar ‘Griotte’ of Portugal were described by Pliny and Virgil (Hedrick 1915; Janick 2011). As a matter of fact, majority of the sweet cherry cultivars grown in the modern times differ from their wild types by only a few generations (Iezzoni et al. 1990; Wunsch and Hormaza 2002).

With more than 30 species identified so far, *P. avium* and *P. cerasus* are cultivated globally that belong to the Amygdaloideae subfamily of Rosaceae (Webster and Looney 1996; Iezzoni 2008; Hummer and Janick 2009). Among the two species, *P. avium* originated from the Caspian and Black Seas and could be native to it or introduced in the Neolithic and Bronze Ages (5500–4000 BC) and later spread to the European temperate regions. As evidenced by the fossils, *P. cerasus* is also believed to be originated from the Caspian Sea and native to northwest and central Europe.

The cultivation of sweet and sour cherry cultivars in North America was particularly based on seeds and budwood (Janick 2011; Wunsch and Hormaza 2002). The sweet cultivars included ‘Napoleon,’ ‘English Morello,’ ‘Bigarreau’ (also known as ‘Royal Ann’), and ‘Bing’ and ‘Yan’ (Hedrick 1915). In America, the ‘Bing’ cultivar is one of the highly cultivated cultivars in the modern times. Among the sour cultivars, ‘Montmorency’ (from Montmorency Valley of France) is the principal cultivar grown in North America (Janick 2011).

2.1.2 Production

Due to recent consumer awareness of fruit consumption, the production of cherries has tremendously increased owing to its health benefits and antioxidant properties. Over the past 16 years (2000–2016), sweet cherry production has increased worldwide from 1.9 to 2.32 million tons, with Turkey, the USA, Iran, Italy, and Spain as the main producers accounting for over 50% of the total global production and the USA, Turkey, and Chile the main exporters (FAOSTAT 2017). Globally, Turkey is the leading producer of cherry with an annual production of 500,000 MT

(FAOSTAT 2017). Cherries are grown mainly in the Marmara region, which is near Istanbul, and Central Anatolia, which is the center of Turkey. There are more than 100 varieties of sweet cherries produced in Turkey (FAOSTAT 2017). Diverse sour cherries are widely distributed throughout the world, such as North America, Europe, and Asia (Wojdyło et al. 2014). The production of sour cherry has increased globally from 1.14to 1.38 million tons from 2006 to 2016. Europe is the largest area of sour cherry harvesting in the world (66%), representing 62% of the total global production. The leading countries for sour cherry production in the world are Russia with a production of 230,443 tons followed by Poland (194,817 tons), Turkey (192,500 tons), Ukraine (156,450 tons), and the USA (140,210 tons) (FAOSTAT 2017).

In India, Cherries are mainly grown in the North-Western Himalayan region in the altitude range of 2000 to 2700 m above sea level and require 1000–1500 h chilling period during winters. The cherry production in India for the year 2017 was estimated to be about 10,852 tons (FAOSTAT 2017). Climate of Jammu and Kashmir (J&K), high hills of Himachal Pradesh, and Uttarakhand is suitable for its commercial cultivation.

2.1.3 Botanical Description

Cherries happen to be the smallest stone fruits that belong to family *Rosaceae*, genus *Prunus,* and subgenera *Cerasus* and *Padus*. On the basis of inflorescence (corymb or racemosa), 100 species of cherries have been classified in two groups. From the subgenus *Cerasus*, the most commonly cultivated *P. avium* (sweet cherry) and *P. cerasus* (sour or tart cherry) have corymb inflorescence. The haploid set of chromosomes in *Prunus* is eight with sweet cherries being diploids and tart cherries being tetraploids (Iezzoni 2008).

Rather than dividing sweet cherries into different subspecies whose characteristic differences are subjected to changes during hybridization, an effective and practicable approach of grouping them on pomological properties involves:

(a) Bigarreaus (firm flesh)
(b) Guigne, Gean, or Heart group (soft flesh)

Based on color, the two groups can be subdivided into dark and light cherries. The black cherries have reddish-purple or mahogany color, while light cherries have yellow to pink color. Likewise, the sour cherries are categorized into two groups including "amarelles" and "morellos," based on skin color, juice color, and fruit shape. The "amarelles" have pale red skin color with colorless fruit juice and flattened fruits. The "morellos" have dark red skin and fruit juice colors with spherical to cordate fruit shapes.

2.2 Antioxidant Properties

Sweet cherries, which are considered as a rich source of dietary phenolic components, play a crucial role in preventing various chronic disorders due to its numerous beneficial health properties (Ferretti et al. 2010; McCune et al. 2011). Recently, tart cherries which are considered as "superfoods" due to its numerous health benefits have been determined over the last 15 years (Maya-Apaza et al. 2017). The antioxidant properties of fruit, juices, seeds, peels, wastes, and its by-products are described below.

2.2.1 Fruits

The antioxidant capacity is due to anthocyanins which are the major phenolic compounds found in cherries. The antioxidant activity of sweet cherry (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid), ABTS, and ferric reducing antioxidant power, FRAP) was reported to be higher in varieties having the highest polyphenolic content, whereas the varieties showed the lowest antioxidant capacities containing low polyphenols and anthocyanin (Nawirska-Olszanska et al. 2017). Phenolic extracts of sweet cherries showed potent antioxidant activity scavenging (2, 2-diphenyl-1-picrylhydrazyl, DPPH, and inhibition of α-glucose oxidase activity in a dose-dependent manner (Goncalves et al. 2017). It has been demonstrated that systolic and diastolic blood pressure and heart rate was found to be lowered in hypertensive subjects while consuming sweet cherry fruit or juice (Kent et al. 2016) as well as various biomarkers suffering from inflammatory disorders in healthy subjects (Kelley et al. 2013). Liyana-Pathirana, Shahidi, and Alasalvar (2006) conducted a study on laurel fruit of cherry and its concentrated juice (pekmez) and proposed that in most cases, pekmez exhibited higher antioxidant capacity as compared to cherry laurel fruit on fresh weight basis, whereas on a dry weight basis, antioxidant property of cherry laurel fruit was higher than pekmez.

Generally, sour cherries exhibited greater antioxidant capacity expressed as oxygen radical absorbance capacity (ORAC) and DPPH as compared to sweet cherries (Pissard et al. 2016). The reverse, i.e., total ORAC, is reported to be higher in sweet cherries as compared to sour cherries (Prior et al. 2016). Recently, a study reported that intake of sour cherries exhibited lowering of oxidative stress inhibited the reactive oxygen species (ROS) formation in human subjects by circulating phagocytes owing to its high polyphenolic content, particularly anthocyanins (Bialasiewicz et al. 2017).

2.2.2 Juices

Historically, pediatricians suggested intake of fruit juices by infants and young children as sources of water and vitamins preventing constipation and for hydration purposes, but the present American Academy of Pediatrics does not recommend addition of fruit juices into infant foods before 12 months of age (Heyman and Abrams 2017).

Sour cherry juice is reported to have neuroprotective effect owing to its antioxidant property and its potential for enzyme inhibition in the central nervous system (Casedas et al. 2016). Casedas et al. (2018) also demonstrated that sour cherry juice prevented cells through reactive oxygen species (ROS) reduction, inhibition of lipid peroxidation, inhibition of H_2O_2-induced toxicity, restoration of GSH to GSSG ratio, and increase in the activity of various antioxidant enzymes. Similarly, sour cherry juice has been shown to be a potent antioxidant because of its capacity to quench both superoxide and DPPH radicals mainly due to the polyphenolic content such as chlorogenic acid and anthocyanins (Casedas et al. 2016). Damar and Eksi (2012) also demonstrated sour cherry to have strong antioxidant activity, which is mainly because of the presence of polyphenols along with anthocyanin fractions including cyanidin-3-rutinoside. Ataie-Jafari et al. (2008) observed total cholesterol lowering, low-density lipoprotein (LDL)-cholesterol lowering and high-density lipoprotein (HDL)-cholesterol increasing effects of sour cherry juice in diabetic women.

2.2.3 Seeds

Cherry processing industry is growing rapidly. However, due to negligible nutrition, recovering of cherry by-products becomes the main obstacle which curbs its further processing in developing countries and also poses environmental concerns (Chen et al. 2014). Therefore, converting by-products into valuable functional components through biotechnological interventions is beneficial. Cherry seeds are the most valuable by-products of cherry fruits and have strong antioxidant property mainly due to the polyphenolic content.

Several studies have investigated the effect of seed extract of sour cherries on cardiovascular diseases (Juhasz et al. 2013; Bak et al. 2006). Various studies conducted on rabbit and rat hearts have shown that sour cherry seed extracts improved its function and reduced the plaque (Juhasz et al. 2013; McCune et al. 2011; Bak et al. 2006). Furthermore, two peptides (Phe-Pro-Glu-Leu-Leu-Ile and Val-Phe-Ala-Ala-Leu) were isolated from cherry seeds that scavenge ABTS, DPPH, superoxide, and hydroxyl radicals. It was contented by the authors that both the peptides had capacity to be used as natural antioxidants (Guo et al. 2015). Similarly, compounds like quercetin and kaempferol pentoside, ellagic acid pentoside, and deoxyhexose found in Brazilian cherry seed extracts were reported to have antioxidant activities (Oliveira et al. 2014). Related with oxygenases, sour cherry seed extract was reported to decrease heme oxygenase-1 and that the regulation of pro-inflammatory signal pathway could be strengthened by the consumption of extract (; Mahmoud et al. 2013, 2014).

2.2.4 Peels and Wastes

Sour cherry pomace is a by-product of juice industries and comprises more than 90% of the fruit on dry weight basis. It comprises mainly of the skin and flesh of the fruit with phytochemicals that are responsible for various bioactive properties (Greiby et al. 2017). It is mainly used as animal feed, fuel, source of extract, as well as for bioactive compound production including anthocyanin and dietary fiber but usually found as waste (Sojka 2010; Kolodziejczyk et al. 2013). Sour cherry pomace has large usage areas in pet foods, snacks, drink mixes, and breakfast cereals possibly because of the presence of bioactive compounds (Greiby et al. 2014), confectionaries, bakery industry, bioactive packaging (Greiby et al. 2013), yogurts, and various functional foods (Kosmala et al. 2009). Powder of the by-product can also be a source of food color.

Sour cherry phenolics have beneficial health-promoting properties including the lowering of β-lactoglobulin allergenicity and inhibition of cardiovascular diseases and cancer cell development. Anthocyanins, which are found abundantly in sour cherry pomace, also show bioactive properties while being nontoxic to living cells (Yilmaz et al. 2015; Bak et al. 2011). Besides phenolic compounds, sour cherry pomace is a good dietary fiber that could prevent colon cancer (Kosmala et al. 2009). Therefore, importance of sour cherry pomace is receiving tremendous attention and could be exploited for its health-promoting potential.

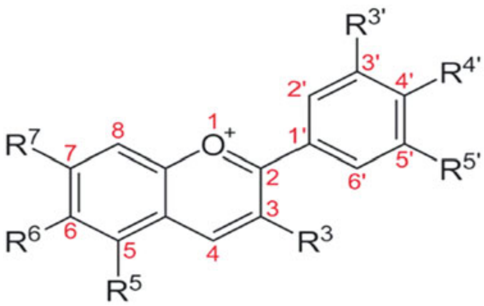
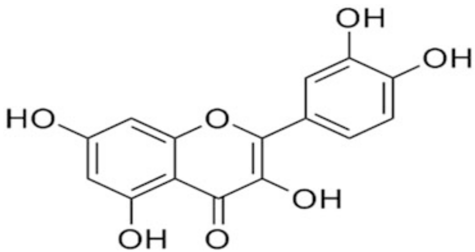
2.3 Characterization of the Chemical Compounds Responsible for Antioxidant Properties and the Pathways Involved in the Biological Activities

Both sweet and sour (tart) cherries are a rich source of polyphenols (McCune et al. 2011; Commisso et al. 2017). The major phenolic components of cherry fruit and their biological properties are presented in Table 2.1. The major anthocyanin compounds in both sweet and tart cherries consist of cyanidin-3-glucoside and cyanidin-3-rutinoside. Apart from the anthocyanins, flavin-3-ols and hydroxycinnamates are present in cherries (Kelley et al. 2006; Wojdylo et al. 2014). Other flavonoids are also present in both sweet and sour cherries (McCune et al. 2011).

2.3.1 Flavonoids

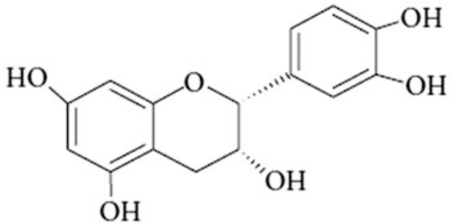
Flavonoids, synthesized by phenyl-propanoid pathway, are ubiquitously found in plants and comprise an enormous category of phenolic components having benzo-γ-pyrone nucleus. Chemically, a skeleton of 15-member carbon atoms with a couple of benzene rings joined by a heterocyclic pyrane ring make up the flavonoids (Fig. 2.1). Flavonoids are further classified into various classes, viz., flavones (like luteolin and apigenin), flavonols (like myricetin, kaempferol,

Table 2.1 Major phenolic compounds in cherries and their biological properties

Bioactive component	Structure	Fruit/plant sources	Biological properties	References
Anthocyanin		Pear, cherries, grapes, red cabbage, and other berries	Anticancerous activity, cardiovascular diseases, antidiabetic activity, anti-inflammatory activity	Kang et al. (2003), Xu et al. (2004), Seymour et al. (2008), and He et al. (2006)
Flavonols (quercetin)		Apples, figs, cherries, chicory, red onion, radish, and lettuce	Vasorelaxant effects, antioxidant, anti-inflammatory, and anticancerous activities	Woodman and Chan, (2004), and Boots et al. (2008)

(continued)

Table 2.1 (continued)

Bioactive component	Structure	Fruit/plant sources	Biological properties	References
Flavanols (catechin, epicatechin)		Apricots, cherries, peaches, apples, blackberries	Antioxidant and antimicrobial activities	Cushnie and Lamb (2005)

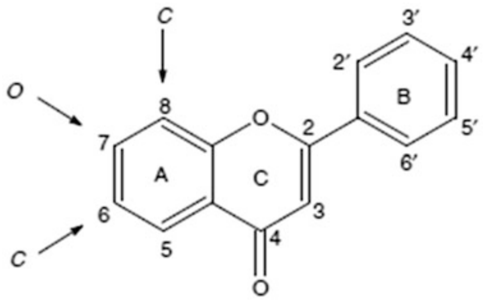


Fig. 2.1 General structure of flavonoids

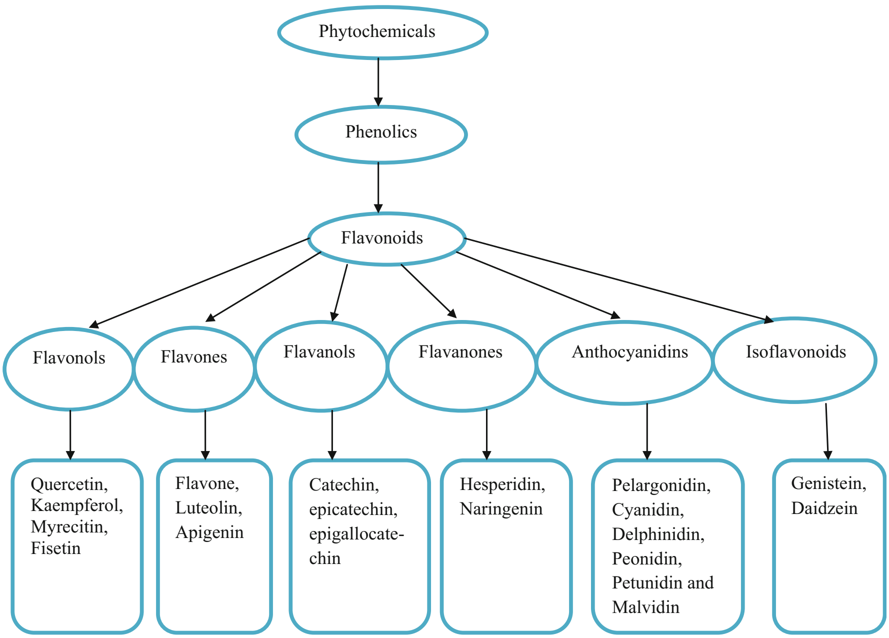


Fig. 2.2 Various bioactive components in cherry fruit

quercetin, and fisetin), flavanones (like hesperidin and naringenin), etc. as shown in Fig. 2.2. Several flavonoid groups vary in the magnitude of the C-ring substitution, while the components within a group vary according to the difference in the substitutional patterns of A and B rings (Middleton 1998). Aglycone is the basic structure of flavonoids where the latter could also be found in the form of glycosides or methylated derivatives. The six-membered ring in flavonols and flavanones involves α-pyrone condensation with benzene or its dihydroderivative in flavonols and flavanones. Depending on the benzenoid substituent at 2- and 3-position, the flavonoid class is subdivided into flavanoids and isoflavonoids, respectively. The hydroxyl groups in flavonoids generally reside at 3, 5, 7, 2, 3′, 4′ and 5′ positions (Narayana et al. 2001). In the glycosides, the sugars involved normally include

D-glucose, galactose, arabinose, glucose rhamnose, or L-rhamnose, and the glycosidic bond is positioned at 3 or 7 (Middleton 1984). The extent of hydroxylation, substitution, conjugation, and polymerization determines the chemistry of flavonoids (Kelly et al. 2002). Anthocyanins such as pelargonidin, delphinidin, cyanidin, peonidin, petunidin, and malvidin and flavonols such as catechins, epicatechins, kaempferols, and quercetin are the main flavonoids found in cherries. Several potential health benefits of these substances arise due to the antioxidant properties of these polyphenolic components, particularly flavonoids (Kumar and Pandey 2012). The antioxidant property of flavonoids is attributed to the functional hydroxyl groups, which act through quenching radicals and/or metal chelation (Kumar et al. 2013). Metal chelation prevents radical generation by damaging target biomolecules (Kumar et al. 2013).

The absorption of the dietary flavonoids released from the ingested food depends on their structural configuration, molecular weight, *pKa*, solubility, and lipophilicity. Most flavonoids are linked to sugars (β-glycosides) except catechins. Aglycone flavonoids are absorbed in the small intestines. However, flavonoid glycosides are converted into aglycans in the colon prior to absorption (Hollman et al. 1999). The hydrophilic flavonoid glucoside-like quercetin is transported across the small intestine by the intestinal Na^+-dependent glucose cotransporter (Hollman et al. 1999). Another mechanism involves hydrolysis of flavonoid glucosides by mitochondrial succinoxidase, lactase phlorizin hydrolase, NADH oxidase, S-transferase, etc. (Brown et al. 1998). Several mechanisms suggest that flavonoids protect lipids against oxidative stress (Kumar and Pandey 2012). Highly reactive hydroxyl radicals can be liberated from the reduction of H_2O_2 as free metal ions ameliorate ROS formation. Flavonoids can donate hydrogen ion and reduce superoxide anion, alkoxyl radical, hydroxyl radical and peroxyl radical. The reaction of flavonoids and the aforementioned radicals is thermodynamically feasible because of low redox potential of the former compared to a high redox potential of the latter. Free radical generation is also inhibited by flavonoids particularly quercetin owing to its capacity of metal ion (copper, iron, etc.) chelation (Mishra et al. 2013). Trace metal ions link to the flavonoids at certain positions in the ring structures (Van et al. 1996). The catechol structure in the B ring firmly enhances inhibition of lipid peroxidation, thereby enabling flavonoids to eliminate superoxide anion, peroxyl radicals, and peroxynitrite radicals from the living system (Kelly et al. 2002). The in vitro radical scavenging ability and lipid peroxidation inhibition of epicatechin and rutin have also been determined (Kerry and Abbey 1997). Oxidation on the B ring of flavonoids having catechol group leads to the formation of ortho-semiquinone exhibiting potent scavenging potential, while unstable radicals are formed due to oxidation of flavones that are a weak scavenger (Sekher et al. 2001). One of the striking features responsible for high antioxidant potential of some flavonoids is the double bond at 2–3 position in conjugation with 4-oxo. The conjugation between A and B rings results in flavonoid radical stabilization due to resonance. Thus, the potential of flavonoids for quenching free radicals is because of different functional elements and structural characteristics (Rice-Evans et al. 1996). The antioxidant potential of aglycon flavonoids is more than the glycosides. However, the latter are more bioavailable (Tapas et al. 2008).

2.3.2 Anthocyanins

Anthocyanins are red-blue-colored water-soluble pigment compounds whose accumulation in fruits and vegetables is considered as an index of maturity. These belong to the polyphenolic subclass of flavonoids and occur in glycosylated forms (Kong et al. 2003; Khoo et al. 2017). There are as many as 31 anthocyanidins discovered so far, of which cyanidin, pelargonidin, peonidin, delphinidin, malvidin, and petunidin represent 90% of anthocyanins. Several investigations related to anthocyanins are focused upon their antioxidant capacity and associated beneficial health implications (Pojer et al. 2013). According to the first report on cherry anthocyanins by Gao and Mazza (1995), cyanidin 3-O-rutinoside and cyanidin 3-O-glucoside represent the major, while peonidin 3-O-rutinoside, pelargonidin 3-O-rutinoside, and peonidin 3-O-glucoside represent the minor anthocyanins. So far, cherries have just been reported to differ in anthocyanin quantity rather than the type of anthocyanin present in a particular variety (Chao et al. 2015). Cyanidin 3-O-sophoroside, cyanidin 3-O-glucoside, cyanidin 3-O-rutinoside, and cyanidin 3-O-glucosylrutinoside were initially reported from sour cherries and account for 77–87% of the total anthocyanins (Kim et al. 2005).

The antioxidant property of cherry extracts has been demonstrated broadly using various methodological tools. Plant bioactive components such as phenolics have numerous health beneficial effects. Among the several types of phenolics, anthocyanins found in cherry have shown possible key roles in the prevention of different disorders (Nikkhah et al. 2008). The stability and antioxidant capacity of an anthocyanin depends on its structure and availability of free hydroxyl groups on the pyrone ring and methoxyl groups (Muselik et al. 2007). A particular orientation in the ring structure could enhance the proton donating ability of the anthocyanin from the hydroxyl groups to neutralize the free radicals (Kay 2004). Likewise, the oxygen radical scavenging ability of delphinidine is higher than cyanidin and pelargonidin, whereas pelargonidin has the highest hydroxyl radical scavenging ability (Antal et al. 2003). The metal chelating activity of anthocyanins corresponds to the 3′, 4′-dihydroxy groups (Sarma et al. 1997). The hydroxyl radical scavenging ability of anthocyanins corresponds to the ortho-dihydroxyl groups (Bakowska-Barczak 2005). Anthocyanins are most susceptible to nucleophilic degradation at the second and fourth position around pH of 2–4. In the last decades, scavenging free radicals by anthocyanins have been hypothesized through two pathways. The first pathway involves linkage of the attacking hydroxyl group(s) to the anthocyanin B ring. In the second pathway, the oxonium ion is linked to the C ring of the anthocyanin. Both these mechanisms work equally well for the anthocyanins during the free radical scavenging reactions.

2.4 Health Benefits

In food science, the literature quoted a range of bioactive components in cherries including anthocyanins, hydoxycinnamates, and flavonoids. Therefore, amelioration in health by consuming cherry is not surprising. Various studies on animals and humans regarded that while consuming cherries, the stake of various chronic disorders such as cancer, diabetes, cardiovascular diseases (CVDs), and arthritis may get mitigated (De Lima et al. 2015; Bell et al. 2014; McCune et al. 2011).

2.4.1 Anticancerous Activity

Various cancer-preventive components are found in sweet cherries such as pigments (anthocyanins and carotenoids), fiber, and ascorbic acid. Anthocyanins, especially cyanidin, play a vital role in cancer risk reduction. Diverse studies have been focused on anticancer activity of cherries containing anthocyanins. The administration of (1) a diet containing cherry, (2) cyanidin, (3) anthocyanins, (4) diet for control, or (5) diet for control with incorporated sulindac (an agent having anti-inflammatory property) indicates that any of the three test diets showed less volume of cecal tumors when fed to mice, but not tumors concerned with colon, than sulindac supplemented or control mice, suggesting that the site-specific inhibition of cecal tumors is mainly due to the bioactivity of cyanidin (Kang et al. 2003). Similar studies have delineated that cyanidglucosides have cancer-protective effects employing apoptotic effects and cancer cell lines through G2/M growth cycle arrest (Chen et al. 2005). Acquaviva et al. (2003) contemplated the positive effect of cyanidin and cyanidin-3-O-β-D-glucoside on impediment of xanthine oxidase activity, DNA cleavage and enhancement in free radical scavenging activity relying on dose. Apoptosis of mutated cells and detainment of cell cycle were studied using cancer cell lines, when unveiled to cherry anthocyanins (Shih et al. 2005; Lazze et al. 2004).

Further, cherry components have shown significant inhibitory effects on epidermal growth factor receptor which may be due to the growth detention characteristics of cyanidin (Meiers et al. 2001). Cellular differentiation is also promoted by cyanidin and thus lowers the risk of malignant transformation (Serafino et al. 2004). In a mouse colorectal cancer model, the volume of cecal tumors was reduced by the use of sour cherries containing anthocyanin-rich extract, suggesting that site-specific inhibition of cecal tumors was only because of the presence of cyanidin (Bobe et al. 2006). The anti-inflammatory activities of cherry-based beverage were reported to abate the risk of chronic diseases, especially in aged populations (Delgado et al. 2012).

2.4.2 Cardiovascular Diseases (CVDs)

Consumption of sweet or sour cherries has been shown to pose cardioprotective effects. Cyanidin-3-glucoside has been shown to lower down oxidative stress by increasing the output of nitric oxide (Xu et al. 2004). Upon exposing the hearts of rats to ischemic injury and then subjecting to extracts of tart cherry at several doses, the incidences of heart attacks and rapid and irregular heart rates were reduced (Bak et al. 2006). Cholesterol gets removed from macrophages and the corresponding foam cells upon treatment with cyanidin-3-O-β-glucoside (Xia et al. 2005). In a randomized, double-blind crossover study involving 12 healthy males, increase in plasma vanillic and protocatechuic acids was observed after intake of 'Montmorency' tart cherry juice concentrates for 1 hour. In vitro increment in vascular smooth muscle cell (VSMC) migration was because of the higher levels of these acids in plasma that may possibly benefit remodelling of blood vessels (Keane et al. 2016a). Moreover, lowering of systolic blood pressure was also reported due to the use of single dose of cherry concentrate with no effect on cognitive functions (Keane et al. 2016b).

2.4.3 Antidiabetic Activity

Supplementation of healthy subjects with cherries or their products shows no effect on fasting or random blood glucose level or fasting insulin. Recently, the diabetes control has received a considerable interest due to the role played by glycemic index (GI). Sweet cherry has been proved to be a potentially better fruit for people associated with diabetes due to the estimated GI of 22, which is lower than apricots (GI of 57), blueberries (GI of 40), grapes (GI of 46), peaches (GI of 42), or plums (GI of 39). The lower glycemic response of cherries is attributed to their bioactive compounds and dietary fiber (Kelley et al. 2006; Garrido et al. 2013). Intake of sweet and tart cherry extracts prevented alloxan-induced diabetes in rats and mice (Lachin 2014; Saleh et al. 2017). High-fat diets introduced with cherry extract or purified anthocyanins reduced circulating glucose, insulin, and liver triglycerides in rats and mice (Snyder et al. 2016; Seymour et al. 2008). Several risk factors were reduced in Dahl rats, suffering from metabolic syndrome and type 2 diabetes risks due to the use of tart cherry-enriched diet (; Seymour et al. 2008, 2009). However, the supplementation of a high-fat diet with anthocyanin extracts from sweet cherry caused obesity and insulin resistance in C57BL/6 mice (Wu et al. 2014).

The α-glucosidase enzyme that carries out the process of sugar absorption is inhibited by several cultivars of sweet cherries or their aqueous extracts (Goncalves et al. 2017). Likewise, chlorogenic acid, one of the main polyphenols found in tart cherry juice, inhibits α-glucosidase and dipeptidyl peptidase-4 enzymes (Casedas et al. 2016; Crepaldi et al. 2007).

2.4.4 Arthritis

The common form of arthritis is gout, characterized by regular attacks of swelling, pain, and redness in joints. The formation of uric acid in the bloodstream and its crystal deposition in joints lead to gout. For decades, cherries have been quietly used to soothe the symptoms of arthritis and gout sufferers, who routinely consume the fruit. Indeed, in the 1950s, it was first proposed that the cherries might assist a relation with arthritis and gout. Preliminary studies have revealed that the gout and pain related to arthritis were relieved due to the daily consumption of cherries (approximately 4.5 cups of cherries). Intake of fresh and canned cherries resulted in attainment of normal uric acid level in the plasma and improved joint movements in toes and fingers in some patients (Blau 1950).

Consumption of as much as 45 sweet cherries has been reported to reduce the plasma markers of oxidative stress and inflammation (Jacob et al. 2003). Moreover, the researchers reported decrease in the plasma uric acid concentration to a significant level only after 5 hours of cherry consumption. Intake of tart cherry juice for a period of 4 weeks also showed significant reduction of plasma uric acid concentration in obese subjects (Martin et al. 2011). However, no change was observed in osteoarthritis patients even up to 6 weeks (Schumacher et al. 2013).

2.4.5 Anti-inflammatory Activity

The bioactive components of cherry pose anti-inflammatory effect via inhibition of the cyclooxygenase (COX) inflammatory enzymes. Among the cherry phenolic compounds, cyanidin and malvidin are the most potent for the inhibition of COX-1 and COX-2 activities (Seeram et al. 2003). Consumption of cherry has been shown to lower down the inflammation in arthritic animal models via decreased production of TNFα (He et al. 2006). Intake of sweet cherry has been shown to lower down plasma IL-18 and ferritin while increasing the IL-1R antagonist in human beings (Kelley et al. 2013). Consumption of tart cherry has also been shown to lower down IL-6, IL-8, and TNFα in human plasma normally produced after a heavy exercise (Levers et al. 2015, 2016).

2.5 Conclusion

The popularity of sweet and sour cherries is growing day by day due to their bioactive properties. The worldwide production of sweet and sour cherries has been increasing rapidly over the last couple of decades that indicates its potential as a horticultural crop. Besides cherry fruits, its processed products such as juice and by-products including seeds and peels also contain high amounts of bioactive compounds with antioxidant properties. Anthocyanins from cherries exert anti-inflammatory, anticancerous, and antidiabetic effects through scavenging the radicals of different types, enhancement of the activities of various antioxidant enzymes, and inhibition of different enzymes responsible for glucose absorption. Cherries offer different food and medical applications and are a good prospect for further research.

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Phalsa (*Grewia asiatica* L.)

3

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Abstract

The subject of the plant-food approach as remedy for oxidation-related health disorders has been on the rise in recent years. *Grewia asiatica* Linn, conventionally known as phalsa, is one fruit of remarkable nutritional profile and health functionalities. It is prominent especially in the Asian continent for the prevention and/or treatment of bodily disorders and metabolic syndromes due to its phytochemical composition. This chapter comprehensively discusses the historical and agronomical details of the plant, along with its geographical locations where it is abundantly available. The antioxidative phytochemistry of its parts, solvent extraction processes, and extensive analytical operations conducted in several studies are also textualized. More importantly, typical health issues where these constituents have been experimentally tested for efficacy are also discussed.

Keywords

Phalsa · Antioxidants · Phytochemicals · Health benefits · Functional food

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3.1 Introduction

3.1.1 History

The *Grewia asiatica* plant is a drought-resistant, shrubby dicotyledon, which belongs to the Grewioideae family. It has approximately 150 species globally distributed and is the sole constituent of the Malvaceae (subfamily) taxonomy bearing edible fruits. The *Grewia* genus (Table 3.1) obtained its name from its taxonomical founder, Nehemiah Grew, and being of the Asian origin, the species name *asiatica* was derived (Zia-Ul-Haq et al. 2013). The genus *Grewia* typically thrives in warm climates and experiences severe leaf losses in the winter. The development of its fruit is noted by color changes, and optimal ripening is closely related with hot or warm temperatures commonly supplied by abundant sunlight (Vyas et al. 2016) With regard to genealogical studies, it is believed that *G. asiatica* is indigenous to the Southeast Asia and Indian subcontinent and also commercially grown in the western and northern regions of India (Singh and Singh 2018). Archaeological reports of phyto-history and fossil materials suggest that it is of the Indian origin and other regions of Asia, probably the southeastern countries like Bangladesh, Sri Lanka, and Pakistan. At the beginning of the twentieth century, Philippines and Indonesia naturalized *G. asiatica* woody fossils of this plant from the Deccan intertrappean beds (sedimentary beds formed underwater) of India confirm its existence from the Early Tertiary period or during the Late Cretaceous period (67–65 million years old) (Shukla et al. 2016). These reports support the speculation that phalsa is of the Indian origin. Models of paleogeography suggest that there was migration of the plant to Africa and Southeast Asia during the Late Tertiary period.

Grewia asiatica L., a shrub, has length usually about 4–5 mm with gray stem, rough bark, cordate to ovate shape leaves approximately 5–18 cm long and 15 cm wide and broad and yellowish flowers arranged in cymes of several together. The plant is mostly cultivated for grayish purple fruit, which is a drupe (fibrous and fleshy). This fruit at full ripening possesses black round and depressed spots on the surface with massive and symmetrical housing trichomes, and the remaining portion of its surface is covered with little trichomes (Jyoti et al. 2015). A single fruit

Table 3.1 Botanical description of *Grewia asiatica*

Kingdom	Plantae
Order	Malvales
Family	Grewioideae
Genus	*Grewia*
Species	*Asiatica*
Common name	Falsa or phalsa
Synonyms	Shukri (Gujarati), chadicha (Malayalam), unnu (Tamil), phalsa (Hindi, Urdu, Marathi), phutiki (Telugu), phulsa (Kannada)

contains 1–2 seeds with a stony hard seed coat. In India, two separate kinds, dwarf and tall, have been groomed with their own distinct physical and chemical properties.

3.2 Distribution

Phalsa is an ideal crop for arid and hot regions. It is preferred for dry land horticulture and silvi-horticulture and can be grown successfully on the slop of hills as well. In India, phalsa plant is known to be grown throughout greater part of Central India, northern Punjab, Bengal, Bihar, Chota Nagpur, Orissa, Himalayas, Gujarat, and Konkan, despite being cultivated commercially in Sri Lanka, Pakistan, and Bangladesh.

3.3 Nutritional Value of Phalsa Fruit from Different Studies

The nutritional composition of phalsa is shown in Table 3.2. Varieties of phalsa bear several phytochemicals located in different vegetative parts such as flowers, leaves, bark, stem, and even in pomace (Paul 2015). These phytochemicals bear different flavonoids, different steroids, glycosides, saponins, functional acids, and alkaloids and have been isolated by many researchers. The total phenolics, for example, differ based on the solvent employed for extraction and are also associated with the vegetative part from which it is extracted such as peel, pulp, or seed.

Table 3.2 Nutritional composition of *Grewia asiatica*

Nutrients (100 g)	Prakash et al. (2009)	Yadav et al. (1999)
Moisture (%)	80.8	–
Protein (g)	1.5	1.6
Lipids (g)	0.9	0.1
Carbohydrate (g)	21.1	21.1
Fiber (g)	1.2	5.53
Ash (g)	–	1.1
Calcium (mg)	129	136
Phosphorus (mg)	39	24.2
Iron (mg)	3.1	1.08
Potassium (mg)	375	372
Sodium (mg)		17.3
Vitamin A (μg)		16.11
Thiamin (mg)		0.02
Riboflavin (mg)		0.26
Niacin (mg)		0.83
Vitamin C (mg)		4.38

Grewia asiatica is composed of the anthocyanins (cyanidin-3-glucoside), dietary fibers, minerals, and vitamin C (Singh et al. 2008). Nutrient studies on *Grewia asiatica* have shown the availability of campesterol (2.15%), alpha-methyl-1-sorboside (11.52%), citric acid trimethyl ester (5.10%), stigmasterol (1.23%), methyl ester (0.10%), and 9,12-octadecadienoic acid (Jyoti et al. 2015). The oil in phalsa seeds is of a bright-yellow color and occupies about 5% oil with a composition of oleic acid (13.4%), stearic acid (11.0%), palmitic acid (8.3%), unsaponifiable material (2.8%), and linoleic acid (64.5%) (Lim 2012). In a study, GC-MS (gas chromatography-mass spectrometry) was adopted for the isolation of 2-(1-oxopropyl)benzoic acid, a comparable component of functionality present in the prominent pharmaceutical aspirin (2-(acetyloxy)benzoic acid) in Jwarhar Mahakashay Ayurvedic formulation of which *Grewia asiatica* is a constituent (Jyoti et al. 2015). Total soluble solids and pigments have been obtained from its pomace, and qualitative evaluation has shown the occupancy of tannins, sugars, alkaloids, flavonoids, steroids, and phenolic compounds (Zia-Ul-Haq et al. 2013).

3.4 Food and Pharmacological Uses of *Grewia asiatica*

Being a fruit, it is edible as a dessert or used for the formulation of beverages such as juices, squashes, syrups, and carbonated drinks, but for concerns of rapid fermentation, sodium benzoate is added to retard its yeast fermentation and extend its shelf life (Singh and Singh 2018). Saddozai et al. (2015) examined the shelf life of freshly prepared phalsa juice packaged in sterilized bottles and stored at room temperature for 2 weeks. Their study showed an increase in yeast count from 0.26 CFU/ml to 0.55 CFU/ml with a remarkable decline in the organoleptic quality and overall acceptability of the juice from sensory analysis. An indigenous drink to the Indian people named *phalsay ka sharbat* is prepared from phalsa, and due to its low glycemic index, the drink is functional for the management of diabetes and to reduce the risks of obesity and coronary heart disease (Zia-Ul-Haq et al. 2013).

3.4.1 Rheumatism

Rheumatism is a collective term for health disorders fostering chronic and frequently sporadic pains that impacts connective tissues and/or bodily joints. Common symptoms include energy loss, tiredness, stiffness and aches at the joints, and mild fever, with associated risks of cardiovascular disorder and death if not offered proper and timely medical attention (Jamnitski et al. 2012).

Extracts from plant parts such as stems, leaves, fruits, flowers, barks, and branches of kunzala (*Carthamus oxyacantha* M.), black mustard (*Brassica nigra*), camelthorn (*Alhagi maurorum*), *Aloe vera*, phalsa, and baneberry (*Actaea spicata*) have been found traditionally beneficial for the management of rheumatism (Kamal et al. 2016). Singhal, Khare, and Yadav (2017) conducted an ethnomedicinal field study within five Indian villages, and from their questionnaire survey, they found out from the local indigenes that the leaf and root extracts of phalsa were functional for rheumatism and wound healing.

3.4.2 Hyperglycemia and Diabetes

Type 2 diabetes mellitus is a metabolic syndrome disorder typified by the body's incapability to metabolize insulin, with a consequent rise in blood sugar and other deleterious effects in the well-being of the body (Kehinde and Sharma 2020). Hyperglycemia is a closely related condition implying a blood sugar level above 11.1 mmol/l. Several in vivo studies with laboratory rats and humans and in vitro studies with biochemical assays of digestive enzymes have confirmed the activities of extracts of plant parts as therapeutic agents for type 2 diabetes mellitus (Ponnanikajamideen et al. 2019; Eruygur et al. 2019). Alcoholic and aqueous extracts of leaves, barks, rhizomes, and fruit pulps of phalsa, lemon balm (*Melissa officinalis* L.), mango ginger (*Curcuma amada*), and wild blackberries (*Rubus grandifolius* L.), among several other plants, have been scientifically proven to have antidiabetic properties (Spínola et al. 2019; Sarkar et al. 2019; Asadi et al. 2019). Common antidiabetic mechanisms have been by the inhibition of digestive enzymes like dipeptidyl peptidase-4 (DPP4), α-amylase, and α-glucosidase in vivo and in vitro (Kehinde and Sharma 2020). Das et al. (2012) examined the antidiabetic potential of the aqueous extract of phalsa fruit on the basis of its in vitro inhibition of α-glucosidase. Their study proved that the extract bore a remarkable half maximal inhibitory concentration (IC50) value of 0.41 mg fresh wt/ml. Khattab et al. (2015) performed an extensive experimentation involving the adoption of phalsa fruit methanolic extract for the treatment of diabetes in rats intravenously administered with streptozotocin (an agent that induces hyperglycemia). Their results showed a decrease in the blood glucose levels of the rats after treatment.

3.4.3 Cardiovascular Health Issues

Cardiovascular diseases (CVDs) are a group of health disorders such as rheumatic heart disease, heart failure, coronary artery disease, peripheral artery disease, heart arrhythmia, valvular heart disease, and so forth, involving the heart or blood circulation organelles (Sachs et al. 2016). They are among the most prominent noncommunicable diseases in contemporary times. The consumption of meat and other processed foods in particular has been linked to CVDs in several researches (Bovalino et al. 2016; Guasch-Ferré et al. 2019). Fruits and vegetables have been health choices for the management of CVD-related concerts due to their natural abundant composition of phytonutrients such as organosulfur compounds, ellagitannins, resveratrol, carotenoids, and isothiocyanates (Bhardwaj et al. 2014). Typical metabolomic mechanisms for actuating improved cardiovascular health by phytochemicals are reduction in blood pressure, inhibition of the blood clotting process through the prevention of platelet agglutination, and reduction in the body's cholesterol profile (Andriani et al. 2015; Rodriguez-Casado 2016). Significant decreases in the ratios between low-density lipoprotein (LDL) and high-density lipoprotein (HDL), total cholesterol and HDL, and the overall amounts of total cholesterol and LDLs have been identified in several research investigations as medical-pharmacological effects of consuming fruits and vegetables (Bhardwaj et al. 2014; Aguilera et al. 2015). Rahman et al. (2013) performed a research to determine the in vivo effect of a beverage made from phalsa fruit powder on the hearts of laboratory animals. The drink was orally administered in dosages of 0.90 and 0.45 g/kg body weight, respectively, and for both dosages, the drink was found to impart no harmful effects on the examined hearts. Zia-Ul-Haq et al. (2013) carried out a thorough analysis on the phytochemical constituents of phalsa seeds and reported the presence of several heart-friendly phytochemical compounds like β-sitosterol, α-tocopherol, and unsaturated fatty acids.

3.4.4 Cancer

Cancer is a collective name for a group of noncommunicable diseases characterized by the abnormal division and growth of cells which are also capable of spreading, proliferating, or invading different body parts (Li et al. 2016). Common cancer locations in the body are the liver, male prostate gland, colon, lungs, and female breasts (Jung et al. 2015). Their prominent physiological characteristics include continual and multiplicative growth pattern, evading natural inhibitors of cellular growth, contravening apoptosis, fomenting angiogenesis, and initiating metastasis and proliferation. Plant foods of high polyphenolic and overall antioxidant contents have been beneficial for cancer treatment. The extracts obtained from fruits, leaves, seeds, and other plant parts have experimentally proven to impart this effect. Conventional fruits like apple, berries, pear, and grapes are rich in antioxidants and consequently serviceable for cancer management (Gadkari and Balaraman 2015). These phytochemicals destroy cancer cells through one or more mechanisms with the overall similarity of arresting the cellular cycle of cancer cells and actuating their natural death (apoptosis) (Roleira et al. 2015). Phalsa, being naturally loaded with antioxidants, has been studied for this purpose. Kakoti et al. (2011) examined the antitumor potential and in vitro cytotoxicity of the methanolic extract of dried phalsa leaves against the cell lines of Ehrlich cells, technically referred to as Ehrlich-Lettre ascites carcinoma (EAC). Their study methodology followed was on the basis of the life span of tumor-bearing laboratory animals, dosed with the extract by intraperitoneal administration. At dosage amounts of 500 and 250 mg/kg of the methanolic extract, their life spans increased by 61.06 and 41.22%, respectively. Cytotoxicity results against cancerous cell lines of HeLa, breast cancer cell line (MCF-7), and leukemia cell lines (K-562 and HL-60) in vitro were 177.8, 199.5, 54.9, and 53.7 μg/ml, respectively.

3.4.5 Miscellaneous Physiological Benefits

With regard to health benefits, phalsa is multifunctional. Virtually every part of the plant (fruits, leaves, barks, roots, and seeds) has been employed as raw materials for the extraction of bioactive phytochemicals. In recent years, numerous research studies have been conducted to investigate and confirm these health-related activities in vivo and in vitro. They include antipyretic, radioprotective, antiviral, anti-inflammatory, antiemetic, antihyperglycemic, antioxidative, and analgesic, among several others (Zia-Ul-Haq et al. 2013; Jyoti et al. 2015).

Akhtar et al. (2016) conducted a study involving the evaluation of the aqueous and methanolic fruit extracts of phalsa for their anti-inflammatory, antipyretic, and analgesic effects in vivo using albino mice. The animals in different test groups were initially injected with 0.5 mL of 1% carrageenan solution to induce inflammation, 300 mg/kg acetic acid as the analgesia, and brewer's yeast solution for pyrexia. Their study showed that both extracts at oral administration amounts of 125, 250, and 500 mg/kg showed significant dose-dependent inhibitions for the effects.

Zia-Ul-Haq et al. (2012) conducted an ethnopharmacological study on the antiemetic, antidiabetic, and antimalarial potentials of the methanolic extract of phalsa leaves. The antiemetic activity was evaluated in vivo using male chicks, while others were tested in vitro on the basis of the extract's inhibition of biochemical assays. The inhibition of the digestive enzymes (α-amylase and α-glucosidase) was used for antidiabetic measurement and enoyl-ACP reductase with crotonyl as a coenzyme was for the antimalarial evaluation. Positive readings were obtained, thus confirming the attribute of the extract for the management of diabetes, emesis, and malaria.

Sharma and Sisodia (2010) performed a histopathological investigation on the radioprotective characteristic of phalsa fruit extract on the testes of Swiss albino mice. The effect of the extract on preventing the weight loss of the testes after exposure to radiation was the basis of the study. Their results showed that relative to the control treatments (without extract), the extract-treated testes had lesser weight loss, 30 days after exposure.

Israr et al. (2012) performed an investigation on the antipathogenic potential of methanolic extracts derived from phalsa (fruit and bark) using two gram-negative bacterial strains (*Escherichia coli* and *Proteus vulgaris*) and a gram-positive strain (*Staphylococcus aureus*). The zones of inhibition measured from the Petri plates were 6.33 ± 0.471, 7.33 ± 0.84, and 6.33 ± 0.849 mm for *Escherichia coli*, *Proteus vulgaris*, and *Staphylococcus aureus*, respectively, results attributed possibly to the chemical nature of the parts used containing compounds such as alkaloids and tetratriacontane.

3.5 Polyphenolic Constitution of Phalsa

Polyphenols have been technically described as the broad class of chemicals with the distinctive features of phenolic units in their chemical configuration and their biological functionality as antioxidants. They are biological macromolecules with aromatic rings, present in nearly all plant taxonomies, moderately soluble in water, and prominently known for their astringent flavor. They can be classified based on their aglyconic chemical structures as flavonoids which include chalcones, neoflavonoids, isoflavones, flavanonols, flavanones, flavonols, flavones, proanthocyanidins, flavanols, anthocyanidins (pelargonidin, delphinidin, and cyanidin and the second prominent group as phenolic acids, cinnamic and benzoic acids), and, finally, polyphenolic amides (avenanthramides and capsaicinoids) (Tsao 2010).

Polyphenols, especially due to their remarkable antioxidant functionality, in recent years, have been of interest in diverse subjects such as nutricosmetics, pharmaceuticals, nutraceuticals, and food processing especially for the formulation of novel products of formidable health impacts. The availability of polyphenols from animal sources has been confirmed by some recent studies in which polyphenols have productively isolated from tea insect, albeit through the usage of complex analytical techniques. Nonetheless, the commercial-scale natural isolation of polyphenols has been from plant parts with readily available solvents.

3.5.1 Flavonoids

Flavonoids are phytonutrients typified with the presence of three aromatic rings (one heterocyclic and two phenyl) in their structure having distinct patterns of glycosylation, methylation, and hydroxylation (Lei et al. 2018). They function as antioxidants through enzymatic inhibition or enhancement, simply by retarding the actions of prooxidative enzymes such as catalase, xanthine oxidase, and NADPH oxidase or by improving the functionality of antioxidant enzymes (Ballard and Maróstica 2019).

Few studies have been recently conducted for the determination of the total flavonoid content from phalsa parts. Sharma and Patni conducted a research on the comparative amount of total flavonoid content present in extracts obtained from old callus, steam, and leaf parts using in vitro and in vivo approaches. Aqueous, alcoholic (ethanol), and chloroform extracts were used, and their chromatographic analyses revealed that the ethanolic leaf extract of all preparations had the maximum quantity with quercetin present in the amount of 4.28 ng/μl and for the callus, 2.42 ng/μl. Khatune et al. (2016) in a study determined the quantity of the total flavonoid content on phalsa bark to be 39.11 ± 4.65 mg of quercetin/gm of dried plant extract.

Chalcones are subclasses of flavonoids, chemically defined as 1,3-diphenyl-2-propen-1-one structurally characterized with the presence of two aromatic rings held together by an unsaturated carbonyl system (Chavan et al. 2016). They are biochemically recognized as the precursors for the metabolism of some isoflavonoids and flavonoids, and due to their occurrence in food materials such as bean sprouts, potatoes, phalsa, tomatoes, and shallot, they are referred to as dietary polyphenols (Mojzer et al. 2016). They have been proven to efficiently possess antibacterial, antioxidative, cytotoxic, and anti-inflammatory potentials. Their anti-cancer potential, however, seems to bear prominence relative to other plant-based foods due to their formidable anticancer mechanisms on cancer cells including imparting significant damage to the mitochondria and DNA, initiation of cellular apoptosis, and inhibition of kinases, tubulin, and angiogenesis (Orlikova et al. 2011; Das and Manna 2016).

Wani et al. performed a biotechnological study of cloning two chalcone synthase isoform genes from phalsa and examined their flavonoid contents. The genes GaCHS2 (NCBI acc. KX129911) and GaCHS1 (NCBI acc. KX129910) were successfully cloned, and the flavonoids quercetin and naringenin remarkably quantified. Among other phytochemicals, chalcone was isolated from a closely related plant, *Grewia microcos* Linn, by Joshi, Bhobe, and Sattarkar. Ethanolic extracts of the plant roots were prepared and analyzed for their phytochemical composition. Their study confirmed the presence of 6,4-dihydroxy-3-propen chalcone, ursolic acid, dibutyl phthalate, dioctyl phthalate, 9,12-octadecadienoic acid, N-methyl-6-β-(1′,3′,5′-trienyl)-3-β-methoxyl-3-β-methyl piperidine, and stigmasterol in the root extracts.

Adebiyi et al. examined the total flavonoid and phenolic content from the stem and leaf methanolic extracts of a closely related species, *Grewia carpinifolia.* The leaf was found to have 9.00 ± 0.13 and 19.08 ± 1.21 GAE/g for the total flavonoid and total phenolic contents, and the stem had 13.22 ± 1.53 and 14.85 ± 1.09 GAE/g for both phytochemicals.

3.5.2 Anthocyanins

Anthocyanins derived their name from two Greek terms, *anthos* and *kyáneos*, which mean flower and blue, respectively, and are basically obtained by sugar addition to anthocyanidins. The uniqueness of anthocyanins from other flavonoids due to their potential to form resonant matrices through pH changes and also because of their color variation, an attribute that makes them applicable as coloring additives in food processing. Talpur et al. (2017) conducted an extensive study on the anthocyanin profile analysis of phalsa fruit using ethanol, methanol, and water as extraction solvents. They reported the presence of a total of seven anthocyanins categorized as pelargonidin-3-O-malonyl glucoside, pyranoanthocyanin (malvidin-3-O-glucoside pyruvic acid), non-acylated (delphinidin-3-O-glucoside, peonidin-3-O-glucoside), and acylated (cyanidin-, peonidin-, and pelargonidin-3-O-6″-acetylglucoside). Remarkable fractions were found to be pelargonidin-3-O-(6″-acetylglucoside), cyanidin-3-O-(6″-acetylglucoside), and peonidin-3-O-glucoside occupying 8–14% (140.4 μg/g), 3–30% (163.6 μg/g), and 44–63% (695 μg/g), respectively. Dave et al. (2015), however, found the anthocyanin content of fresh phalsa fruits to be about 10 μg/g.

3.6 Conclusion

The use of plant materials for health disorders has gained attention in recent times. Phalsa and its parts such as leaves, fruits, stems, barks, and seeds have been proven to possess remarkable antioxidant potentials and, consequently, useful for the prevention and/or treatment of associated disorders. With extracts such as butanol, ethanol, methanol, chloroform, methyl acetate, chloroform, or a mixture of these, several antioxidant bioactive components have been isolated from phalsa. Extracted polyphenols such as anthocyanins, flavonoids, and chalcones, among several others, have been productively separated from aerial parts of the phalsa plant using one or more analytical techniques, and their antioxidative functionalities affirmed with in vivo and in vitro studies. Furthermore, other bioactivities such as antidiabetic, anticancer, antihypertensive, and antirheumatic potentials have been discovered. These investigations prove tentatively the worthy appraisal of phalsa as not just a fruit for food usage but also a functional food possessing numerous health benefits.

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Yellow Himalayan Berry

4

Deep Shikha and Piyush Kashyap

Abstract

The "yellow Himalayan raspberry" (*Rubus ellipticus* Smith), also known as "golden Himalayan raspberry," has been found to be the traditional wild species of the Himalayan regions of India, belonging to the Rosaceae family exhibiting tremendous health-promoting properties including antioxidant, antiproliferative, anti-inflammatory, and antidiabetic properties. As compared to other fruit varieties, this wild variety of fruit is not that much popular as for consumption purposes but as the fruit and its derivative products exhibit so many benefits; therefore, the study of these properties would be advantageous to add on the value to this fruit. The presence of intensified form of numerous chemical compounds, for example, phenolic compounds, flavonoids, flavanols, and anthocyanins, and free radical scavenging power analyzed for in vitro as well as in vivo studies, has been confirmed that its effect is so effective that it can also be compared to other local varieties of fruits available. This chapter focuses mainly on the basics about the species including history, production of plant, biological distribution, and importantly its antioxidant capacity of several portions of fruit and also other benefits. This study also elaborates the presence of abundant chemical compounds available and how they are effective in the pathway of biological activities, mainly free radical scavenging properties.

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Keywords

Yellow Himalayan raspberry · Antioxidant · Antiproliferative · Anti-inflammatory · Antidiabetic

4.1 Introduction

Botanical name: *Rubus ellipticus* Smith
Common name: Yellow Himalayan raspberry; golden Himalayan raspberry
Family: Rose family, Rosaceae (Wagner et al. 1999)

In ancient times, to cure and to relief from diseases, human beings were generally dependent on natural plant sources because of the limitation of the availability of other resources. As epidemiological studies described that presence of plant material, like fruits in human diet attribute to reduction of chronic ailments in humans such as cancer and heart diseases (Ziegler 1991; Law and Morris 1998; Badhani et al. 2015). Prevention causing properties of various wild varieties found popularity in their use due to the presence of a number of polyphenolic contents and other bioactive complexes that have been proven in experimental studies. Wild varieties of plant sources include diverse kinds of fruits such as different types of berry fruits such as blackberry, raspberry, and others. The intake of these fruits strongly shows effects against various chronic illnesses such as diabetes, heart-related diseases, etc.

Similarly, species in the genus *Rubus* of Rosaceae (rose family) have approximately 750 species and 12 subgenera (Finn 2008; Muniyandi et al. 2019; Saklani et al. 2011). This particular genus includes numerous amounts of species that are rich in nutritional value. It has been stated that *Rubus* species are invasive in nature and they have property of resistant mechanism and therefore easily adapt to various environmental conditions. Various studies have been carried out to determine the properties of its various species such as *R. niveus*, *R. fairholmianus*, and *R. ellipticus*. This is a wild variety of fruit and has astringent property. The use of its juice is generally adopted for the treatment of fever, cough, and throat problems, and Tibetan people use its bark for medicinal purposes. The fruit is full of benefits as considered for its medicinal value, but still its properties need to be analyzed. This current study focused on its antioxidant properties as well as the presence of its constituents that contributes to these properties (Saklani et al. 2011; Pandey and Bhatt 2016).

4.1.1 History

Yellow Himalayan raspberry is found in tropical climates or wet forests and is recorded to be originated from the moderate Himalayas region but being native to Southeast Asia and presently can be listed in the areas of Himalayas extending from Pakistan to Nepal to southern China in addition to countries like Burma, India, Bhutan, Myanmar, Philippines, Sri Lanka, and Thailand.

Native species of the yellow Himalayan raspberry *R. hawaiensis* was noticed as an escapee from the fields in 1961. According to the reports of Becking (1979), *R. ellipticus* was brought into Java and had spread in its surrounding areas like Cibodas Mountain Gardens. During a certain period of time, in Florida, it was grown as a type of fruit crop, and in California, it was cultivated as an ornamental crop with the name of golden evergreen raspberry. After this, it was originated into the areas of Malawi, Africa, but it posed a threat to the succession of the natural forest vegetation. From the horticultural viewpoint, it has a high breeding potential, and because of this very potential it was introduced in Hawaii's Volcano Agricultural Experiment Station. At present, Hawaii is facing the great infestation in local areas of volcano community and regions of islands which are in mid-elevation forests. Due to its high propagation capacity by the means of its seeds through the agents like birds and feral mammals, it is feared that it might become established throughout the islands of Hawaii.

4.1.2 Distribution

Rubus ellipticus is a wild variety of raspberry and extensively distributed worldwide as well as some regions of India. Globally, it is found in Asian and African continents and its nearby islands, including Sri Lanka, and some areas in the Philippines where either this species was found to be inherent to the particular region or it was introduced there (Becking 1979).

In India, it is found native to the states of Assam, Sikkim, Tamil Nadu, Kerala, and Maharashtra. The area falling under the Himalayan hills of the north regions of India and Pakistan to the center and south areas of China is found to be the central region for *Rubus ellipticus*. Table 4.1 gives details about the distribution of the

Table 4.1 Distribution table of *Rubus ellipticus* in India and worldwide

Country/region	Distribution	Origin	References
World			
Malawi, Mozambique, South Africa, Tanzania, Indonesia, Costa Rica, Jamaica, California, Florida, Hawaii, Australia, Ecuador	Present	Introduced	Edwards (1985), Prota (2015), Lalla and Cheek (2014), USDA-ARS (2015), Becking (1979), Missouri Botanical Garden (2003), CABI, PIER (2015), Australia, Royal Botanic Gardens Sydney (2007)
Myanmar, Nepal, Philippines, Sri Lanka, Thailand, Vietnam	Present	Native	Becking (1979), USDA-ARS (2015)
India			
Assam	Present		Kalita et al. (2002)
Kerala	Present	Native	India Biodiversity Portal (2016)
Maharashtra	Present	Native	India Biodiversity Portal (2016)
Sikkim	Present	Native	Flora of China Editorial Committee (2015)
Tamil Nadu	Present	Native	India Biodiversity Portal (2016)

species. Gerrish et al. (1992) reported in their studies that spreading of fruit seeds may be because of the consumption of fleshy portion of fruit by birds and feral mammals, but still there is doubt for the ability of fruit to be found all over the Hawaiian Islands.

4.1.3 Botanical Distribution

R. ellipticus (botanical name) is commonly known as golden Himalayan raspberry or yellow Himalayan raspberry belonging to the family of Rosaceae (rose). *Rubus ellipticus* is a brambling raspberry with yellow fruits, inherent to humid and subtropical India as well as Asia. It is a perennial plant raising up to a height of approximately 4.5 m. For the growth of fruit, suitable soils are sandy, loamy, and clay, and the most preferable one is well-drained soil. It can be grown in semi-shade or no shade environment and favors moist soil.

Kingdom: Plantae (plants)
Subkingdom: Tracheobionta (vascular plants)
Infrakingdom: Streptophyta (land plants)
Superdivision: Spermatophyta (seed plants)
Division: Magnoliophyta (flowering plants)
Class: Magnoliopsida (dicotyledons)
Subclass: Rosidae
Order: Rosales
Family: Rosaceae (rose family)
Genus: *Rubus* L. (blackberry)
Species: *Rubus ellipticus* Sm. (yellow Himalayan raspberry; golden Himalayan berry)

Rubus ellipticus is a doughty, feebly mounting, and ever popular shrub which can grow up to 4.5 m or 12 feet. Its branches are of stout type, standing upright, and biennial produced from a woody rootstock. In the first year of growth, the stems produce only leaves and not flowers and form branching outlets in their next year of growth, and these flowering branches die after fruiting. These types of plants can rapidly grow and form tall and dense thickets. Branchlets are brownish or purplish brown in color, with curved prickles, and have purplish brown bristles along with glandular hair. These plants are well suited for growth in sloppy areas, sparse forests, thickets, along waysides, in the canopy of forests, in the deep shade of rainforests, and mostly where land has been disturbed by feral mammals especially pigs.

Leaves are of alternative and compound type with round to blunt leaflets. These are imparipinnate, trifoliate, elliptic, or obviate having minute toothed prickles which are purplish red in color. The underside of the leaves is lighter when compared to the top surface. The terminal leaf size is higher than the lateral leaflets. The thick leaves are 3–4 inches long and 2–3 inches wide. An axially dense tomentose with red

Fig. 4.1 Yellow Himalayan raspberry (*Rubus ellipticus* Smith)

bristles are present along the prominent veins and axially veins are impressed and being pubescent along the midvein (Fig. 4.1).

Flowers are small and short having white color bearing five petals and grow in cluster and bloom in the months of February and April. Flowers are mostly found in leaf axial and are 1–1.5 cm in diameter. Petals are 5 in number which may be white or pink, margins primrose, and base is clawed. Stamens are more numerous than petals and are shorter too, but filaments are broad and compacted basally. Styles are glabrous and are little longer than stamens. Flower is bisexual in nature and is normally pollinated by various insects. The flower later develops into an aggregate fruit which is golden yellow in color and subglobose. The diameter of the fruit is approximately 1 cm. The fruit being a cluster of drupelets can be easily separated from the receptacle when they are mature.

4.2 Antioxidant Properties

Reactive oxygen species, or simply termed as free radicals having single or more than one free electron, are free to react with other molecules for their stability (Uma et al. 2011). These free radicals generated inside the body due to inhalation of certain toxic compounds accidently or intentionally, and/or due to metabolic activities, the presence of these radicals contributes to major chronic diseases such as cancer, diabetes, cardiovascular diseases, dysfunction of the brain, and aging by damaging the cells of the body (Sies et al. 1992; Vendemiale et al. 1999).

Nowadays, people become more conscious about their health as a number of degenerative diseases occur due to the presence of free radicals in human body as it can suppress antioxidants. Increasing awareness about the health problems leads to increase in the use of various nutritional components which are necessary to maintain a healthy body. To solve these problems, a number of investigations suggest that various species of plant basis having good antioxidant properties may have a remedial effect on scavenging reactive oxygen species and prevent damaging the cell membranes (Nagulendran et al. 2007) when compared to synthetic formulations, which may lead to certain side effects. Antioxidant possessions of *R. ellipticus* were also investigated by various researchers, and Uma et al. (2011) found in vitro antioxidant activities in relation to DPPH radical scavenging activity and reducing power methods. The results have revealed that DPPH radical scavenging and reducing power activity was highest with ethanolic extracts depending on the concentration of the extracts used followed by aqueous and petroleum extracts of plant tissues.

4.2.1 Fruit

The extracts of *R. ellipticus* with ethanol have a noble volume of phyto-constituents with effective reducing power activity (93%) as equated to petroleum ether extracts (92%) and aqueous solvents (89%). Antioxidant properties of plant extracts are due to the existence of phenolic and flavonoid compounds. One another research over antioxidant activity of yellow Himalayan berry showed that total phenolics (899.0 ± 4.78 mg GAE/100 g FW) and total flavonoids (433.5 ± 13.39 mg CE/100 g FW) were highest in acid acetone extracts (Meda et al. 2008; Weber et al. 2008).

Antioxidant properties of *R. ellipticus* were analyzed in relation to three parameters like responsive oxygen species scavenging property, β-carotene bleaching inhibitory and ferric decreasing activities. The DPPH free radical (619.3 mg CE/100 g FW) and ABTS cationic radical scavenging (1072.6 mg BHAE/100 g FW) was highest in acetone extract. Ferric reducing action of plant extract depends upon the presence of phenolics to reduce Fe^{3+} to Fe^{2+}, and it was highest with acid acetone extracts and lowest with methanolic extracts, that is, 1389.82 mg AAE/100 g FW and 695.7 mg AAE/100 g FW, respectively.

Antioxidants are molecules which have the capability to donate their electron to reactive species and help make the body free from oxidative species that are responsible for creating chronic diseases in human body. The increasing rate of cancer mortality may be resulted with low plasma antioxidant count (Willett 1994; Nigel Deighton et al. 2000). Fruits and vegetables also possess high antioxidant activity, and it has been proved that they can help in maintaining good health in addition to protect the body from severe disease (Hertog et al. 1993). So with this belief, the use of plant sources has been increased from the past years and includes different classes of berries as blue berries, cranberries, etc. There is one class of berries known as yellow Himalayan berry having a good quantity of antioxidants.

4.2.2 Root

The amount of antioxidants in the root extract of fruits provides health benefits to human life by inhibiting production of free radicals and other DNA damage (Srinivasan et al. 2007). The presence of total phenolic complexes in the root extract of Himalayan berry contributes to antioxidant action as determined by Vadivelan et al. (2009). Different samples were prepared by using several types of solvents to estimate numerous types of phenolic contents in it that results between 21 and 225 mg/g of gallic acid. The maximum amount of total phenols was observed in methanol extract than in petroleum ether extract with lowest concentration. The methanol root extract prepared having a high value of total phenols showed strongest free radical scavenging activity against DPPH and ABTS free radicals in comparison with ascorbic acid. The root extracts were also considered to have a potential of wound healing, dysentery, and other properties.

4.2.3 Leaf

Leaf extracts were also analyzed for its scavenging activity for in vitro and in vivo studies. The results revealed for in vitro studies that RELM extracts can significantly scavenge stable free radical DPPH (6.96 μg/mL) that were analyzed in comparison with other standards such as BHA (4.88 μg/mL), BHT (13.18 μg/mL), and quercetin (4.12 μg/mL), respectively. The inhibition capacity against nitric oxide free radicals and superoxide radicals was found to be 71.08% and 66.08%, respectively (George et al. 2015).

In vitro studies revealed a strong antioxidant activity; therefore, in vivo experiments were also conducted to determine the effectiveness of glutathione activity (GPH), glutathione peroxidase (GPx), catalase activity (CAT), and superoxide dismutase (SOD). It was found that at two different levels of doses of leaf extract that is 100 and 250 mg/kg showed a significant increase in antioxidant activity. The presence of total phenolic content and its antioxidant activity was also studied by Sharma et al. (2014). They found in their studies that among all extracts, methanol extracts have high phenolic content, whereas the least was found in hexane extract, and due to the presence of high total phenols in methanol extracts, it showed high antioxidant activity. So, this states that the presence of various bioactive components is responsible for the antioxidant activity of *Rubus* leaf extracts.

4.2.4 Antioxidant Properties of Products Prepared from Fruit

Fruit juice has also been used to prepare ready to serve (RTS) products and has been analyzed for their basic properties including soluble solids, acidity, and reducing sugars. The product has been studied for determination of the presence of various bioactive components such as ascorbic acid content, phenolic compounds, carotenoids, and total flavonoids in fresh sample as well as during storage studies.

Krishna et al. (2016) analyzed the antioxidant activity of RTS and they reported that storage conditions of ready to serve mainly effects ascorbic acid content and small changes were observed on other chemical compounds such as carotenoids, anthocyanins, and flavonoids. The antioxidant activity of the RTS increased a bit during storage, initially it was 1.4% for fresh sample which increased to 1.5% for first week, but on further increase in storage duration, there was a significant decline in the same. The increase in the value may be due to strong tendency of polyphenolic compounds to undergo various polymerization reactions (Krishna et al. 2016; Piljac-Zegarac et al. 2009; Pinelo et al. 2011).

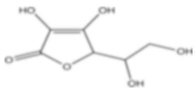
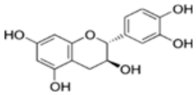
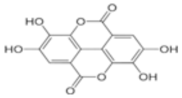
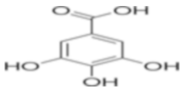
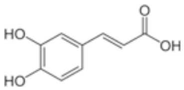
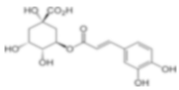
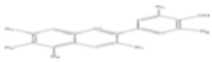
4.3 Characteristics of Chemical Components Responsible for Antioxidant Properties and the Chemical Pathways Involved in Biological Activities

The fruit of yellow Himalayan berry consists of a number of phenolic compounds, phytochemicals, flavonoids, antioxidants, and other bioactive compounds that enhance the nutritive value of the fruit in comparison with other fruits. This wild variety is as not popular as other fruits but has comparative value of antioxidant properties that could help in improving the health of people. Various types of polyphenols and basic components have been analyzed in the *Rubus* species in different research findings that are responsible for antioxidant activities of the Himalayan berry (Table 4.2).

The availability of a huge amount of chemical compounds expresses a positive relationship towards the antioxidant activity of fruit (Sharma and Kumar 2011a, b, c; Badhani et al. 2015; Pandey and Bhatt 2016). Pandey and Bhatt (2016) reported in their studies that the presence of flavonoids is of much concern as per their physiological activities. Extracts of fruit were examined using a high-performance liquid chromatography system equipped with UV-VIS detector (Saini et al. 2014; Rawat et al. 2011) and compared with standards of phenols and flavonoids. The authors found that antioxidant activity relies on the total phenolic content to stabilize free radical DPPH. It was revealed that the scavenging property of DPPH free radical was maximum for acetone extract instead of methanol extract (Saini et al. 2014; Gülçin et al. 2010). Badhani et al. (2011) found that in the Himalayan berry extract, the range of total phenols was 3.95 ± 0.05 mg GAE/100 g, total flavonoids 4.99 ± 0.15, anthocyanin content 0.58 ± 0.02, β-carotene 1.81 ± 0.02, and vitamin C 4.46 ± 0.53. In fresh fruit extracts, two main phenolic acids such as caffeic acid and gallic acid were also found in highest amount of 40.55 mg/100 gm and 40.45 mg/100 gm, respectively.

Various types of extracts were prepared using different types of solvents to examine the antioxidant activity of *Rubus ellipticus*, and it was found that methanol extracts exhibited maximum antioxidant activity having a range between 45.97 and 84% (Ahmad et al. 2015). In epidemiological studies, the inverse relationship between dietary flavonoids and coronary heart diseases proved that the intake of dietary flavonoids would be helpful in the prevention of heart diseases (Hertog et al.

Table 4.2 List of chemical compounds responsible for antioxidant activity of fruit

Sr. no.	Chemical compound	Structure	Resource
1	Beta-carotene		Badhani et al. (2015), Saini et al. (2014), Schulz et al. (2019)
2	Ascorbic acid		Badhani et al. (2015), Saini et al. (2014), Schulz et al. (2019)
3	Catechin		Badhani et al. (2015), Saini et al. (2014), Schulz et al. (2019)
4	Ellagic acid		Badhani et al. (2015), Saini et al. (2014), Schulz et al. (2019)
5	Gallic acid		Badhani et al. (2015), Saini et al. (2014), Schulz et al. (2019)
6	Caffeic acid		Badhani et al. (2015), Saini et al. (2014), Schulz et al. (2019)
7	Chlorogenic acid		Badhani et al. (2015), Saini et al. (2014), Schulz et al. (2019)
8	Anthocyanin		Badhani et al. (2011), Pandey and Bhatt (2016)

1993). Karuppusamy et al. (2011) also studied about the presence of anthocyanin, ascorbic acid, and other bioactive components along with their antioxidant activity. Badhani et al. (2015) reported the relationship between the total phenolic content and the antioxidant activity of the fruit extract by using ABTS, FRAP, and DPPH assays. The studies also have shown a positive relationship between total flavonoids and antioxidant. Since methanol extract in various studies showed the higher content of polyphenols and flavonoids and also exhibited higher antioxidant activity, in some cases, it was also shown that acetone extract showed maximum antioxidant activity that may be for different types of free radicals, but the relationship between the chemical constituents, which include polyphenolic contents, flavonoids, anthocyanins, and other components, is yet to be understood properly (Sharma et al. 2014).

4.4 Health Benefits of *Rubus ellipticus*

The presence of natural organic phytochemical compounds in fruiting species is found normally in the Himalayan region, which provides a considerable nutritional security with remarkable health benefits to humans that helps to promote their good health (Rana et al. 2018). As human diet comprises plant material as their major portion, analysis of nutritive value of such material is important to be known. The genus *Rubus* involves wide genera of plants that comprise 12 subgenera with high-value fruiting species. Sharma and Kumar (2011a, b, c) reported the analysis of phytochemical compounds in *Rubus ellipticus* and found the presence of flavonoids, phenolic compounds, steroids, and tannins that provides various health benefits as it was traditionally used as medicine for wound healing, antimicrobial, and antifertility (Vadivelan et al. 2009; Erdemoglu et al. 2003). Various literature reviews reported the presence of triterpenes in *Rubus* species, which enables anti-inflammatory activity of *Rubus ellipticus*.

4.4.1 Anti-inflammatory Activity

During the early stage of inflammation, the release of chemical compounds takes place such as bradykinin, histamine, and serotonin and on the later stage prostaglandins (Di Rosa et al. 1971; Heller et al. 1998) which leads to increase in vascular permeability and ultimately promotes the collection of cellular fluid in tissues.

Wei Li et al. (2009) have revealed the presence of triterpenoid saponins in *Rubus* species and determined nine different types of triterpenoids and 21 types of saponins which were further classified into seven categories. Vadivelan et al. (2009) reported in their phytochemical studies of ethanol root extract of *Rubus* species the presence of tannins, triterpenoids, and flavonoids. The availability of these compounds showed that an anti-inflammatory effect on edema in rats induced by carrageenan at two different levels of 250 mg and 500 mg/kg was significant after 2 h of ingestion and continued for 2–3 h but no effect was seen with 125 mg/kg even after 6 h.

George et al. (2013) have explained in their studies that 400 mg/kg of methanol extract has potent anti-inflammatory activity and also described analgesic effect in mice in comparison with standard. The studies also found comparable results for antipyretic effect of *Rubus ellipticus* for elevated temperature by activity of yeast in rats as compared to doses of paracetamol (100 mg/kg) (Pandey and Bhatt 2016; George et al. 2013).

4.4.2 Antidiabetic

Diabetes mellitus or simply termed as diabetes for normal people is a type of pancreatic disorder which occurs due to loss in the production of insulin in the body. In human body, β-cells are responsible for the production of insulin and to maintain blood glucose level. This particular disorder can be classified as polyphagia, which results in excessive eating; polyuria, which leads to excessive production of urine; and polydipsia, which effects the thirst of human beings (Sharma and Kumar 2011a, b, c). The antioxidant activity of fruits showed a positive effect on preventing this pancreatic disorder. Therefore, various studies had been carried out to find out the activity of berries.

Sharma and Kumar (2011a, b, c) found in their studies the effect of *Rubus ellipticus* on alloxan-induced rats as well as their glucose tolerance level. They reported that the oral dose of extract of fruits (200 mg/kg) for 15 days showed a significant effect for its activity against diabetes. Fruit juice was extracted using three different solvents including ethanol, petroleum ether, and aqueous solutions, and comparative results were obtained for ethanolic and aqueous extracts than petroleum extracts. It has been reported that plant material shows antihyperglycemic activity by protecting the activity of beta-cell present in the pancreas to absorb maximum glucose and helps in reducing glucose load (Jadhav et al. 2009).

4.4.3 Wound Healing Properties

Whenever any body part gets wounded, several biochemical reactions take place on its own as the wounded area gets exposed to the environment such as inflammation, remodeling phases, etc. (George et al. 2013; MacKay and Miller 2003). The natural human body system is having capacity to regenerate wounded area or having wound healing properties. The wounded area is rich in oxidants or reactive oxygen species (i.e., H_2O_2) generated by the activity of superoxide dismutase (SOD) on superoxide which may also lead to the generation of other oxidants that are responsible to promote these reactions. To overcome this activity of oxidants, the use of antioxidants can be helpful in the reduction of their activity (Khanna et al. 2001). So, the use of various natural resources (i.e., plant materials) made it possible as they are rich in antioxidants. In vitro studies of *Rubus* have proved the antioxidant as well as other pharmacological properties (George et al. 2013).

Studies revealed that a maximum dose of 2 g/kg of extract is an appropriate amount to be used. In one of the study conducted by George et al. (2015), two different doses of extracts were used (i.e., 100 mg/kg and 200 mg/kg). The results for contraction of excision (1.5 cm in diameter, 0.2 cm in depth) of the wound area were noted down at a difference of 3 days started from 3rd day to 21st day, and it was found that the percentage contraction of wound area was significantly increased The contraction percentage was found close to Betadine (100% on the 12th day) with 2% acetone *Rubus ellipticus* extract (94.23% on the 12th day). This study revealed that use of natural extract of *Rubus* species was much effective in wound healing.

4.4.4 Antitumor Properties

The antitumor properties of *Rubus ellipticus* had also been studied for solid tumor induced by carcinoma cells such as Dalton lymphoma ascites (DLA) cells and Ehrlich ascites carcinoma. *Rubus ellipticus* leaf methanol (RELM) extract showed reducing effect in tumor cells. It was shown that treatment of fruit extract at different doses results into a decreased volume of tumor from 3.07 cm^3 to 2.56 cm^3 with an increased volume of extract from 50 to 250 mg/kg b. wt, respectively, for DLA-induced tumor in animals. The effect of leaf extract for EAC cell-induced tumor was also effective to increase the life span of animals at the same concentration (i.e., 50 to 250 mg/kg b. wt) to some extent that is approximately 20 to 45% (George et al. 2015).

4.4.5 Antiproliferative

Some of the studies also analyzed antiproliferative properties of *Rubus ellipticus* by preparing extract using different solvents. The property of inhibition of proliferation of cancer cells is of greater importance as it becomes the most sensitive case for today's generation, and consumption of natural products to overcome this kind of problem is a better choice. The antiproliferative activity of fruit extract has been identified against two different cancer cells and found that fruit extracts (at different doses) were more effective against C33A cells; on the other hand, it did not show any activity against HeLa cells (Saini et al. 2014).

4.4.6 Other Benefits

Yellow Himalayan berry extracts were also analyzed for other properties such as acute toxicity, analgesic activity, antipyretic activity, nephrotoxicity, etc. For acute toxicity, OECD (Organization for Economic Co-operation and Development) guidelines were followed, and in vivo studies were conducted on rats. They were administrated with a dose of 2 g/kg orally and observed for any kind of changes for few hours to several days, and no clinical changes were observed (Vadivelan et al. 2009).

Another study with methanol extracts was also conducted on rats and mice to check the acute toxicity by giving a different range of doses (i.e., 0.1 g, 0.5 g, 1 g, and 2 g/kg) followed by 3 h fasting prior to administration of the extract. The results demonstrated no mortality in the toxicity testing (George et al. 2013).

Analgesic and antipyretic activities of the methanol leaf extracts were also examined at two different doses (i.e., 100 and 200 mg/kg) (George et al. 2013). Both the doses showed prominant results as antipyretic and analgesic as compared to aspirin, morphine, and paracetamol.

4.5 Conclusion

The Himalayan berry (*Rubus ellipticus* Smith) fruit, juice, root, and its derivative were found to be a rich source of antioxidants as studies proved it by various analyses. The extracts of fruit and its various parts consist of a good amount of polyphenolic compounds, flavonoids, anthocyanins, and other bioactive components and have a good nutritional value in terms of crude proteins, carbohydrates, and minerals such as iron, calcium, and magnesium. The presence of these compounds not only provides antioxidant properties but also antiproliferative, analgesic, and anti-inflammatory properties, as studied for in vivo as well as in vitro studies. The fruit is found to be a wild variety having an invasive nature and a huge amount of benefits, but still it is not getting popularity as other local varieties of plant sources even if the fruit is having a comparative range of benefits. Future investigations must be focused to increase the value of fruit in terms of increasing its utilization to cure free radicals as well as other chronic diseases.

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Mangosteen (*Garcinia mangostana* L.)

5

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Abstract

Mangosteen (*Garcinia mangostana*) is grown in tropical rainforests of Southeast Asian countries. The fruit is an all-purpose fruit as all of its parts like aril, pericarp and other components are utilized. This fruit is among the important tropical fruits and is recognized as the queen of tropical fruits for its eye-catching colour and appetizing flavour. It is also well known to cure various ailments and used from centuries in Southeast Asia as a folklore medicine. With increasing interest of researchers in this fruit over the last few decades to confirm its health claims, the natural molecules α-mangostin, xanthones and other bioactive substances are believed to be responsible for its medicinal activities. Physiological disorders stimulated by pre-harvest and postharvest conditions have a key impact on its appearance and consumption. The white aril part of the fruit is edible, palatable, juicy and soft with a sweet pleasing taste. Besides its consumption as raw, the aril is processed to other functional food products. The pericarp of the fruit is rich sources of many functional molecules that may have possible medicinal value. This chapter aims to summarize the cultivation, botanical classification, chemical components and beneficial properties of mangosteen.

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Keywords

Mangosteen · Bioactive components · Antioxidant properties · Antifungal properties · Health benefits

5.1 Botanical Name, Common Names

The botanical name of mangosteen is *Garcinia mangostana* L., which belongs to the family Clusiaceae and the genus *Garcinia, which contains around 35 genera and 800 species*. It is a fruit of tropical Southeast Asia, which was previously categorized in the family Guttiferae. Mangosteen, the 'queen of tropical fruits' 'superfruit' (Mamat et al. 2019), is known with several names across the world. Linnaeus gave the genus name *Garcinia* in honour of the French naturalist 'Laurent Garcin'. Laurent Garcin and other co-workers presented one of the detailed descriptions of mangosteen. Mangosteen derived its name from Malay or Javanese (Fu et al. 2007). Other common names of mangosteen are mangostanier (French), mangostán (Spanish), mangostão (Portuguese), mangostane (German), manggis, masta (Malaysia and Indonesia), mangkhut (Thailand), mangostan (Philippines) and mangostin (India). The fresh fruit of the mangosteen is in huge demand because of its subtle flavours along with the right balance of sweetness and sourness. Nowadays, it is grown extensively in tropical regions of the world and exported to Asian and European countries owing to its unique taste, visual colour, nutritional properties, bioactive components and well-documented health benefits (Gross and Crown 2007).

5.2 Introduction

5.2.1 History

The exact origin of mangosteen is not clear owing to its vast cultivation since ancient period; however, it is believed to be native of Southeast Asia and is commonly found in Malaysia, Sunda Islands and Moluccas regions of Indonesia since the fifteenth century. From its centre of origin, the tree was then established in other tropical areas of the world such as in the north part of Australia, Brazil and some states of Central America, such as Colombia, Hawaii and Florida, along with Southeast Asian countries like Indonesia, Thailand, Philippines and Borneo. In India, it is found primarily in the southwest region of the country (Morten 1987; Nakasone and Paull 1998; Osman and Milan 2006; Ji et al. 2007; Lee et al. 2019).

5.2.2 Production

As per 2018 FAOSTAT, India ranks first in the world production of mango, guava and mangosteen with the production of 21,822,000 MT on 2,258,000 hectares followed by China (4,845,000 MT), Thailand (3,791,000 MT) and Indonesia (3,083,339 MT). Thailand accounts for 90% export of its total production. In Thailand, it is grown on a 51,000-hectare area. Countries such as Pakistan, Mexico, Brazil, Bangladesh and Nigeria are also accounting for world production of mangosteen. In China, it is grown over 667,000 hectare, in Thailand over 427,000 hectare and in Indonesia over 235,000 hectare. It should be noted that the world production on mangosteen is available along with combined data of mango, *mangosteen* and guava in the FAO report. Production of mangosteen has not been documented alone by the Food and Agriculture Organization (FAO) as mangosteen is considered as minor fruit. In another report by the FAO, it has been documented that 50% of world production of mangosteen is regulated by Thailand, which also holds 90% of the world export share of the fruit. In Thailand, it is produced over an area of 51,000 hectares with the production of 200,000 tonnes, followed by Indonesia with an area of 12,000 hectares and production of 105,000 tonnes. Vietnam, Malaysia and Philippines are other main counties producing mangosteen in the world. However, its cultivation is restricted to a limited area in parts of India, Australia and Mexico and is also cultivated on smaller scale in parts of Sri Lanka, Hawaii, Puerto Rico and Costa Rica. Since mangosteen is a tropical fruit, it grows best between the temperatures of not less than 4.4 °C and not more than 37.7 °C with an optimum temperature of 25–35 °C. The tree prefers deep, organic-rich fertile soils with a pH of 5.5–6.8, such as sandy loam soils with good drainage. Generally, the tree requires good humidity (80%) and rainfall of 50 inches with no drought, but in some locations, it is growing in areas where the average rainfall is between 80 and 105 inches. However, care should be taken that such soils should have better water holding capacity (Morton 1987; Osman and Milan 2006). Mangosteen is limited to grow at elevations of 500–1500 m above sea level, with the best growth at 500–600 m, and above these elevations, the tree growth is retarded and slow (Osman and Milan 2006).

5.3 Botanical Description

Mangosteen, a slow-growing dioecious evergreen tree with an upright trunk, belongs to the family Clusiaceae of the genus *Garcinia* L., which has 35 genera and more than 800 species. *Garcinia mangostana* L., is a short to medium height tree which goes from 6 to 25 m with a trunk width of 25–35 cm, brown to black bark, having asymmetrical branches which help to form a pyramidal crown (Te-Chato and Lim 2006; Osman and Milan 2006). The tree bears 4–6 cm wide male, female or hermaphrodite green to red colour flowers in a cluster of 3–9, having 4 sepals and petals along with rudimentary stamens and lobed stigma. It takes usually 4–6 months depending on region, from flowering to fruit set, fruit maturation and finally ripening. The tree bears globose-shaped berry-type parthenogenetically formed fruits which are crowned by calyx on stem side and 5–8 lobes of woody stigma remnants at the apex end. Mangosteen fruits are usually spherical or slightly flattened, smooth surfaced with an average diameter of 3.5–8.0 cm and a weight of 75–150 g, seedless

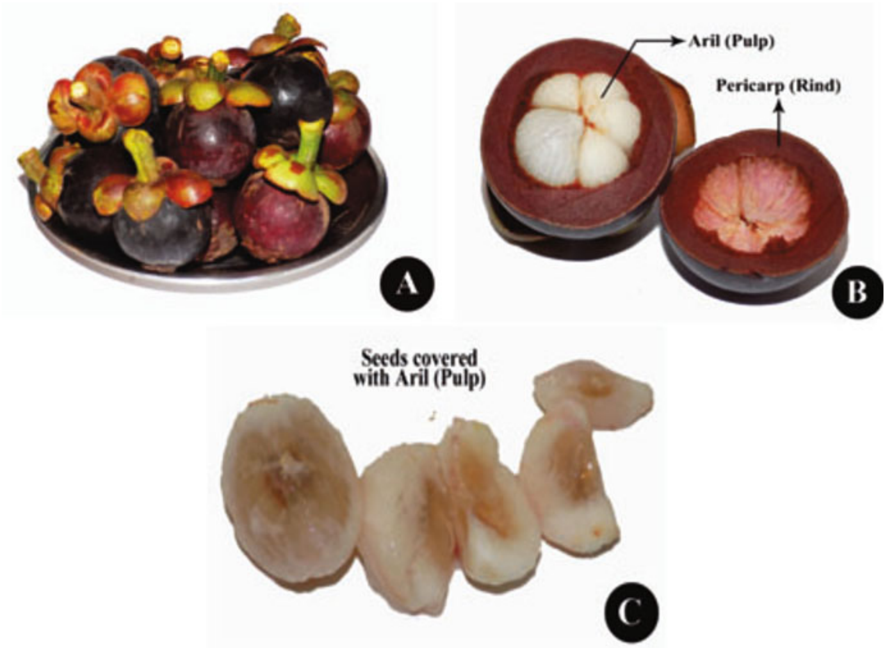

Fig. 5.1 Fruits of *Garcinia* species. (**a**) Fruits. (**b**) Cross section of fruit showing aril and pericarp. (**c**) Arils. (Source: Murthy et al. 2018)

or with 1–5 ovoid-oblong shaped seeds having a length of 2.5 cm and a width of 1.6 cm. The physiological characteristics of the fruits vary with the age and geographical location of the tree (Noichinda et al. 2019). Mangosteen fruits are generally having exocarp of dark purple to reddish, with juicy white fleshy pulp enclosed within 4–8 triangular sweet aril (Fig. 5.1). The flesh of the fruit is a rich source of anthocyanins, a red pigment. Aril which is the edible portion of the fruit accounts for 25–30% of the fruit having a TSS of 15–19%, with distinctly sweet acidic taste and flavour predominantly due to formation of ester (cis-3-hexenyl acetate), alcohol (cis-3-hexen-1-ol) and hexyl acetate components (Ramage et al. 2004; Osman and Milan 2006; Parthasarathy and Nandakishore 2014; Ayman et al. 2019).

5.4 Chemical Constituents

Mangosteen is a packhouse of phenolic phytochemicals and has high antioxidant properties (Lee et al. 2019). The chemical constituents xanthones and anthocyanins are the major polyphenol compounds reported in the fruit (Mamat et al. 2019). To date, 60–70 derivatives of xanthone have been extracted, isolated, identified and characterized in the whole fruit, stem, aril, pericarp and leaves. Oxygenated and prenylated xanthones are the main polyphenol and secondary metabolites present in the fruits due to which the fruit exerts its bioactive properties. Among xanthones which are present in the fruit, the most predominant is α-mangostin which makes 69% of total xanthones followed by β- and γ-mangostin, gartanine, garcinone E and 8-deoxygartanin (Fig. 5.2) (Pedraza-Chaverri et al. 2008). The cyanidin-3-sophoroside and cyanidin-3-glucoside are the main anthocyanins found in the fruit pericarp. Other than these, xanthonoids and 10 phenolic acids have also been recognized in different parts of the fruits, and among these, protocatechuic acid is predominant in peel and rind, while p-hydroxybenzoic acid is primarily present in aril tissue (Ayman et al. 2019). A significant amount of terpenes, condensed tannins, minerals (calcium, phosphorus, iron) and vitamin B (B1, B2 and B3) is also present in the various parts of the mangosteen fruit. The list of characterized xanthones in different morphological parts of the mangosteen is summarized in Table 5.1.

5.5 Bioactive Components of Mangosteen and Their Activity

Compounds and extracts in the pure form obtained from *G. mangostana*, mainly xanthones, are known to possess a large diversity of pharmacological activities such as antibacterial, antifungal, antioxidant, antihistamine, anti-inflammatory, cytotoxic and other activities (Table 5.2).

5.5.1 Antioxidant Activity

Mangosteen fruits are established as an attractive source of active molecules with huge biological compounds. Mangosteen mainly possesses oxygenated and prenylated xanthones which possess various antioxidant activities (Mbwambo et al. 2006; Chen et al. 2010; Jawed et al. 2010). All the botanical parts of the mangosteen such as fruit, peel/pericarp, seeds, leaves, rind and bark exhibit good antioxidant activity (Pedraza-Chaverri et al. 2008). Antioxidant activity of rind and peel measured by DPPH, FRAP and ABTS assays was manyfold higher in comparison to the edible fruit or aril (Naczk et al. 2011). α-, β- and γ-Mangostin are major xanthones which possess variable antioxidant activities in different parts of the mangosteen (Fig. 5.2). When compared with 27 fruits of Singapore market, the antioxidant activity, which was measured as DPPH quenching potential, TBARS assay and 2,2-azino-bis-(3-ethylbenzthiazoline-6-sulfonic acid) assay, was higher compared to most of the tropical fruits and stands at eighth position among all the fruits. They observed that the mangosteen extract had the eighth place with respect to the antioxidant efficiency and can quench 50% of the free radicals (Pedraza-Chaverri et al. 2008). Gartanine, garcinone D and E, garcimangosone B, 1-isomangostin, smeathxanthone A, 8-hydroxycudraxanthone G, mangostingone, mangostinone, tovophyllin A, 8-deoxygartanin and cudraxanthone G are the xanthone compounds which also exhibited antioxidant activity. Antioxidant properties of the mangosteen provide protection against LDL oxidation.

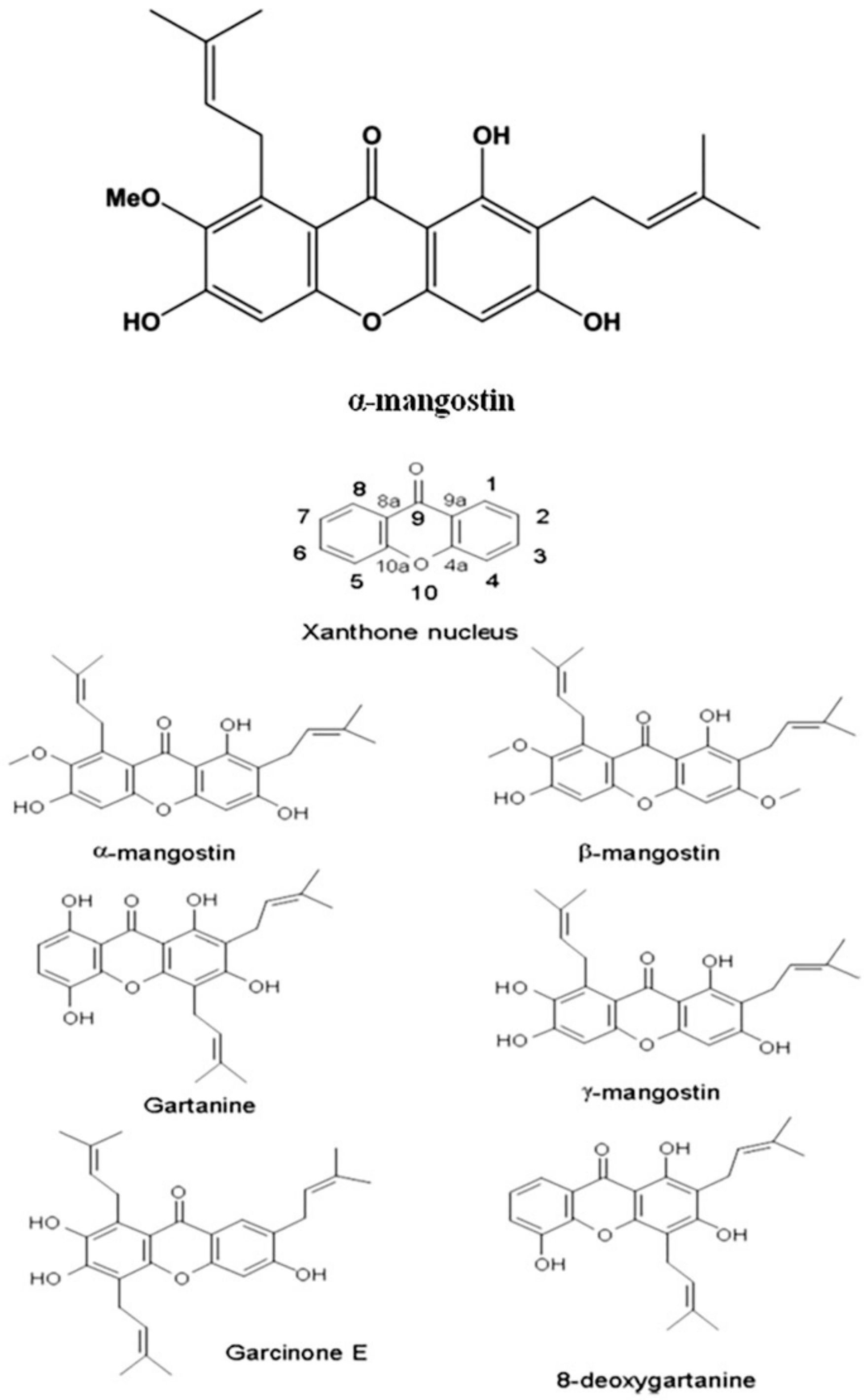

Fig. 5.2 Structures of different xanthones in mangosteen. Source: Gutierrez-Orozco and Failla (2013)

Table 5.1 Secondary metabolites of *G. mangostana*

Compound name	Plant part	References
Xanthones α-Mangostin	Whole fruit, aril, pericarp, seed and stem	Chen et al. (2008)
β-Mangostin	Stem, pericarp, whole fruit	Ee et al. (2006)
γ-Mangostin	Pericarp, whole fruit	Jung et al. (2006)
1,8,10-Trihydroxy-2-(2-hydroxypropan-2-yl)-9-(3-methylbut-2-enyl)-1,2-dihydrofuro[3,2-a] xanthen-11-one	Whole fruit	Chin et al. (2008)
1,3,6,7-Tetrahydroxyxanthone	Heartwood	Farnsworth and Bunyapraphatsara (1992)
1,3,6,7-Tetrahydroxy-2,8-(3-methyl-2-butenyl) xanthone P1	Pericarp	Yu et al. (2007)
1,5,8-Trihydroxy-3-methoxy-2-(3-methylbut-2-enyl) xanthone	Leaves	Farnsworth and Bunyapraphatsara (1992)
5,9-Dihydroxy-8-methoxy-2,2-dimethyl-7-(3-methylbut-2-enyl)-2H,6Hpyrano-[3,2,6]-xanthene-6-one	Fruit hull	Ee et al. (2006)
Demethylcalabaxanthone	Arils, whole fruit, seed	Suksamrarn et al. (2003)

Source: Obolskiy et al. (2009)

Due to the antioxidant properties exerted by various compounds of the mangosteen, it is used for the management of various chronic diseases such as lipid peroxidation, cancer, inflammatory issues, etc.

5.5.2 Antifungal and Antibacterial Activities

Extracts from *G. mangostana* as well as various xanthones possess strong antibacterial and antifungal activities. Gopalakrishnan et al. (1997) tested the antifungal behaviour of naturally present xanthones in mangosteen fruit against three strains of pathogenic fungi (i.e. *Alternaria tenuis*, *Fusarium oxysporum* and *Drechslera oryzae*) and documented a relationship between the structure and biological properties. The isoprenyl groups along with the hydroxyl groups of phenolics present in ring A and ring B had a considerable effect in exhibiting the antifungal mechanism of xanthones. The variability of the position and presence of the functional groups in rings A and B affected the extent of inhibition. γ-Mangostin was reported to be the most active component among various compounds being tested against all the fungi samples under examination. The antibacterial action of α-mangostin against the virulent *Enterococci* and *Staphylococcus aureus* was tested by Sakagami et al. (2005), and they reported that α-mangostin had an inhibitory

Table 5.2 *G. mangostana* extracts and their pharmacological activities

Extract/ compound	Uses	References
	Antioxidant activity	
Chloroform extract of the pericarp	Antioxidative effect	Puripattanavong et al. (2006)
Ethanolic extract of the pericarp	Antioxidant properties confirmed by DPPH scavenging and NBT reduction assays	Chomnawang et al. (2007)
α-Mangostin	α-Mangostin acts as a free radical terminator to prevent the low-density lipoproteins from oxidation	Williams et al. (1995)
α-Mangostin and its derivatives	Inhibition of low-density lipoprotein oxidation	Mahabusarakam et al. (2000)
	Antifungal activity	
Ethanolic extracts of the pericarp	Antifungal action against common tinea species like *Trichophyton mentagrophytes*, *Trichophyton rubrum* and *Microsporum gypseum*	Puripattanavong et al. (2006)
α-Mangostin γ-Mangostin	Acts as antifungal agents against *Fusarium oxysporum*, *Dreschlera oryzae* and *Alternaria tenius*	Gopalakrishnan et al. (1997)
	Antibacterial activity	
γ-Mangostin Garcinone D Mangostanin α-Mangostin	Potent against the bacterium *Mycobacterium tuberculosis*	Suksamrarn et al. (2003)
α, β and γ-Mangostin	Virulent against the strains of *Staphylococcus aureus*	Farnsworth and Bunyapraphatsara (1992)
	Anti-inflammatory activity	
γ-Mangostin α-Mangostin	Cyclooxygenase inhibition and inhibits prostaglandin E2 synthesis Anti-inflammatory action by inhibiting the inducible NO synthase	Chen et al. (2008)
	Antihistamine activity	
α- and γ-Mangostin	Acts as histaminergic and serotonergic receptor blocking agents	Chairungsrilerd et al. (1996)
Anti-HIV activities α-Mangostin	Non-competitive inhibition against HIV-1 protease enzyme	Chen et al. (1996)
Other pharmacological uses		
Ethyl acetate extract of the stem	Stops the larval growth of *Aedes aegypti* mosquito	Ee et al. (2006)
Xanthones	Potent antimalarial agents Effective against the *Plasmodium* digestive vacuole	Riscoe et al. (2005)

action against five strains of *Enterococci* with a minimal inhibitory concentration value of 6.25 μg/mL and nine strains of *Staphylococcus aureus* with a MIC (minimal inhibitory concentration) value of 12.5 μg/mL. Another report documented the synergistic effect of α-mangostin and antibiotics which are commercially available. α-Mangostin either singly or in combination with gentamicin was reported to act against vancomycin-resistant enterococci (VRE), whereas in combination with vancomycin hydrochloride, it was potent against methicillin-resistant *Staphylococcus aureus* (MRSA). Hence, it is proved to be useful and recommended for various in vivo tests and inhibiting the VRE and MRSA infections. Prenylated xanthones extracted from the arils, seeds and fruit hull of *G. mangostana* were tested against strain H37Ra, and its combination with α- and β-mangostin possesses a very strong antituberculosis potency having MIC values of 6.25 μg/mL. Suksamrarn et al. (2003) reported a correlation between structure and efficacy and asserted that xanthones with tri- and tetra-oxygenated structures along with C5 isoprenyl units are essential for their antimycobacterial activity.

5.6 Methods for Estimation of Antioxidant Properties

Antioxidants are molecules that can prevent, delay or stop the onset of free radical generation by inhibiting the initiation and/or propagation steps of oxidation. The selection of antioxidant assay for the estimation of antioxidant potential is done on the basis of the type of free radical generated during the process. The common criteria for the selection of antioxidant method are the single electron transfer (SET) and hydrogen atom transfer (HAT) mechanism (Phipps et al. 2007). Selection of the analytical method for evaluating the antioxidant properties depends on the mode of oxidation. The estimation of antioxidant activity of mangosteen can be evaluated as free radical scavenging potential, reducing power, chelation ability and lipid oxidation inhibition based on quantitative measurement of the antioxidants. The estimation of antioxidant properties of mangosteen can be done by following the protocols like 1,1-diphenyl-2-picrylhydrazyl radical assay, (2,2-azino-bis-(3-ethylbenzthiazoline-6-sulfonic acid) radical assay, nitric oxide radical (NO^*) assay, hydroxyl radical (OH^*) assay, oxygen radical absorbance capacity and ferric reducing antioxidant power; the details of these methods are easily available and are well documented.

5.6.1 Antioxidant Properties of Mangosteen Fruit and Juice

Mangosteen to a large extent remained confined to domestic consumption for a long time. In recent years, the trend has changed and there are numerous commercialized mangosteen products, for example, canned, frozen, freeze-dried and dehydrated mangosteen arils, jam, wine and pasteurized juice available in the market globally. The most prominent commercialized products available in the market are the juice blends which consist of whole fruit of mangosteen pureed and other combination ingredients. Mangosteen arils are being consumed in Thailand as fresh fruit and juice, and also in desserts. It is claimed to have an antioxidative, anti-inflammatory and protective effect on neurodegenerative diseases. However, current reports revealed limited clinical efficacy (Udani et al. 2009) and possible toxicity (i.e. severe lactic acidosis) (Wong and Klemmer 2008). Consequently, interests are shifting from the blended mangosteen juices to mangosteen juice from the aril. However, there is a need for further exploration of the health benefits from the aril part of the fruit. The antioxidant and cytoprotective activities of squeezed mangosteen juice were studied to provide the basic health-related information for consumer and manufacturer. The total phenolic, ascorbic acid and tannic acid contents of mangosteen juice are 18.54 mg GAE/100 g, 7.08 mg/100 g and 84.77 mg/100 g, respectively.

Antioxidant properties of mangosteen were basically due to the presence of xanthones and its derivatives. Several studies reported that the antioxidant of mangosteen fruit was basically due to yellow coloured α-mangostin which is the first isolated xanthone from mangosteen (Pedraza-Chaverrı et al. 2008). α-Mangostin helps to lower down the LDL oxidation caused by peroxy radicals and α-tocopherol. Other than xanthoses, antioxidant activities of the mangosteen juice are primarily due to anthocyanins and flavonoids. Mangosteen juice exhibited efficient antigenotoxic potential with no genotoxicity. It also significantly inhibited micronucleated polychromatic erythrocytes induced by daunorubicin when administered along with free radical inductor agent and also exhibited maximum DNA damage protection activity (Burguete et al. 2016). Macias et al. (2017) in their study reported that mangosteen juice exhibited cytotoxic potential over different cell lines mainly in healthcare antioxidant. Mangosteen juice reduced the polychromatic erythrocytes by 85% when administrated at 0.2 mL for 72 h. Xanthone and its derivatives possess various health-promoting compounds and exhibit human health benefits such as antibacterial, antimicrobial, anti-inflammatory and anticarcinogenic activities and same are documented in Table 5.3. Moongkarndi et al. (2004) in their study reported that mangosteen crude methanolic extract exhibited significantly higher antioxidant properties as it reduced the reactive oxygen species production in the human breast cancer (SKBR3) cell line in a dose- and time-dependent manner. Fruits of mangosteen phenolics have antioxidant potential as the aril of mangosteen exhibits the antioxidant potential of 14.6 mM Trolox/g GAE and EC50 values of 1347 μg/assay and 10.2 μg GAE/assay (Naczk et al. 2011). The edible aril of the mangosteen fruit had total phenolics of 9.3 mg GAE/g and condensed tannins of 42.2 AU/g of extract. Mangosteen pulp along with the mixture of guava leaves, *Lycium barbarum* and *Momordica grosvenori* significantly increased the antioxidant activity of the yoghurt in comparison to plain yoghurt (Shori et al. 2018). Characterization and quantification of xanthones from aril and functional beverage containing the extract of mangosteen by HPLC-DAD-MS revealed that mangosteen aril had 1,7-dihydroxy-3-methoxy-2-(3-methylbut-2-enyl) xanthone (65.88 mg/100 g), γ-mangostin (43.39 mg/100 g), α-mangostin (21.3 mg/100 g), 8-deoxygartanin (26.39 mg/100 g), gartanine (28.92 mg/100 g), garcinone E (48.70 mg/100 g) and 1,3,7-trihydroxy-2,8-di-(3-methylbut-2-enyl)xanthone

Table 5.3 Sources and biological activity of mangosteen xanthones

Xanthone sources	Biological activities	References
Xanthones and its derivatives	Xanthones have anticancer activity, play a role in enzyme modulation, have antimicrobial activity, act as central nervous system depressants, potent against the neurological dysfunction, are anticonvulsant, act as an analgesic, as antiarrhythmic, as antihypertensive, anti-inflammatory, antiallergic and in some immunomodulatory activities	Pinto et al. (2005)
Whole fruit, pericarp, aril, seeds, heartwood, leaves and branches	Acts as antiallergic, antibacterial, anticancer and antifungal. Cytotoxic, provides immunity against HIV. Anti-inflammatory, antimalarial, antioxidant and antiviral Acts as a central nervous system depressant, maintains cardiovascular health and antiulcer activities	Pedraza-Chaverri et al. (2008), Chin and Kinghorn (2008) Obolskiy et al. (2009)
Mangosteen extracts	Acts as potent anti-inflammatory, invasive, metastatic and cancer management, pro-apoptotic, arrest cell cycle during cell division	Shan et al. (2011)

Source: Sukma et al. (2011)

(1.35 mg/100 g) which had antioxidant properties. Antioxidant properties of fruits are basically due to their phenolic content and phenolic acids. Mangosteen aril exhibits a total phenolic content of 6.4 g/kg GAE, 9.7% free phenolic acids and 265.7 mg/kg total phenolic acids (Zadernowski et al. 2009). They also reported that the predominant phenolic acid in the aril is p-hydroxybenzoic acid. The focus is mostly on new research keeping in view the metabolism and bioavailability of xanthones, and their anti-tumour and anti-inflammation activities, and their known effects on cellular signalling pathways.

It was found that mangosteen juice showed reducing power capacity while tested using ABTS, FRAP and DPPH assays, but it was not able to scavenge the galvinoxyl radical. The results suggested that mangosteen juice has an antioxidant capacity which is mainly observed using the SET-based reaction. H_2O_2, OH·, O_2-, HOCl and ONOO- are the major reactive oxygen species which cause human health damage (Jellinger 2007). It was found that mangosteen juice could scavenge OH·, O_2-, ONOO- and HOCl free radicals. However, the scavenging effects on O_2 and H_2O_2 were not found while L-ascorbic acid and butylated hydroxytoluene (BHT), reference substances, showed scavenging effects on O_2 and H_2O_2 with IC_{50} values of 0.42 mg/mL and 272.91 ± 1.61 μg/mL, respectively (Table 5.4).

To further investigate the antioxidant property of mangosteen juice, iron ion chelating activity was evaluated. Ferrous iron (Fe2+) is very important in the Fenton reaction to give the OH· which is extremely harmful to the human body (Jellinger 2007). It was found that mangosteen juice (1–10 mg/mL) did not show ion chelating

Table 5.4 Antioxidant activities of mangosteen juice

Test/sample		MJ (mg/mL)	Reference	
Total antioxidant capacity	ABTS (IC_{50})	0.23 ± 0.46	1.27 ± 0.46 μg/mL	Trolox
	FRAP (EC_1)	301.10 ± 8.37	115.61 ± 12.51 μg/mL	Trolox
	DPPH (IC_{50})	1.91 ± 0.65	1.27 ± 0.10 μg/mL	L-ascorbic acid
Ion chelating –	(IC_{50})	–	3.89 ± 1.60 μM	EDTA
Radical scavenging	Hydroxyl (IC_{50})	1.99 ± 0.10	6.71 ± 0.20 mM	Mannitol
	Superoxide (IC_{50})	2.41 ± 0.85	1.13 ± 0.20 μg/mL	L-ascorbic acid
	Peroxynitrite (IC_{50})	0.21 ± 0.03	0.21 ± 0.03 mM	Gallic acid
	Singlet oxygen (IC_{50})	–	0.42 ± 0.03 mg/mL	L-ascorbic acid
	Hydrogen peroxide (IC_{50})	–	272.91 ± 1.61 μg/mL	BHT

MJ mangosteen juice, *BHT* butylated hydroxytoluene

activity while EDTA, a reference substance, showed positive results with the IC_{50} value of 3.89 ± 1.60 μM. Lim et al. (2007) reported the low chelating power of 50% ethanolic extract of the edible portion of mangosteen. From the aforementioned experiments, it can be presumed that mangosteen juice has antioxidant activities. Mangosteen juice also had a scavenging effect on OH·, O_2-, ONOO- and HOCl. Numerous reports are supporting the neurotoxicity of OH·, O_2-, ONOO- and HOCl (Jellinger 2007).

5.6.2 Antioxidant Properties of Mangosteen Leaves

Very few reports examined the antioxidant potential of leaves (Pedraza-Chaverri et al. 2008). The essential components extracted from leaves of mangosteen are 1-hydroxy-6-acetoxy-3-methoxy-2-isoprenylxanthone, 1,6-dihydroxy-3-methoxy-2-isoprenyl-xanthone and gartanine, and these molecules exhibit potent antioxidant properties. A glycoside 2-ethyl-3-methylmaleimide N-β-D-glucopyranoside is a flavour compound which was extracted from mangosteen leaves (Krajewski et al. 1996).

5.6.3 Antioxidant Properties of Peel/Pericarp/Rind

Among all the morphological fractions of the mangosteen fruit, mangosteen pericarp or mangosteen rind, peel, hull a food processing waste, was reported to have highest antioxidant potential due to its higher total phenolic content and anthocyanins (Naczk et al. 2011; Suttirak and Manurakchinakorn 2012). The total phenolic content of mangosteen hull is 245.78 mg GAE/g and anthocyanin content of 2.92 mg *cy-3-glu*/g. The antioxidant activity of ascorbic acid from mangosteen rind is 3.39 (IC_{50} value) and mangosteen rind pectin is 161.93 (IC_{50} value) due to the hydroxyl group of the polysaccharides, and it can be potentially utilized in biomedical operations as a low methylated pectin biopolymer with antioxidant activities. The pericarp of mangosteen is a rich source of hydrophobic polyphenol compound (α-mangostin) with superior antioxidant activity. The pericarp of mangosteen exhibits 83.63% and 93.77% inhibition power of DPPH and ABTS radicals, respectively, along with 144.56 mg Trolox equivalent/g as FRAP assay with a total phenolic content of 320.31 mg GAE/g. The outer pericarp of mangosteen had a total phenolic content of 29.30 mg GAE/g, while the inner pericarp had a significantly higher total phenolic content of 34.04 mg GAE/g (Chaovanalikit et al. 2012). Antioxidant activity has a significant positive correlation with the prevention of human health disease. Tjahjani et al. observed that the antioxidant activity in terms of IC_{50} (μg/mL) was highest for samples extracted by hexane and alcoholic extract of mangosteen. The total antioxidant capacity of hexane fraction was also higher as compared to other extraction solvents and concluded that mangosteen rind exerts potential antioxidant activities. Antioxidant activity in terms of ABTS and RSA was measured using EC_{50} and was found that the methanolic extract of mangosteen pericarp has a value of 142.04 μg/mL. The chief secondary metabolite of the mangosteen pericarp is xanthones, tricyclic aromatic compounds, which had various medicinal properties. Out of the 70 total xanthones found in the mangosteen, approximately 50 of them are found in the pericarp of the fruit at significantly higher concentration in comparison to its aril and prominent xanthones among them are α-, β- and γ-mangostin, gartanine and garcinone A, B, C, D and E (Obolskiy et al. 2009). The total phenolic content of 140.66 mg GAE/g was also reported in mangosteen hull by Cheok et al. Mangosteen peel extract also exerts a significant positive effect on the reduction of lipid oxidation and oil rancidity during accelerated storage of refined sunflower oil at higher storage temperature and thus helps to enhance the shelf life of the oil. In its legal limit, mangosteen peel can be used and recommended as a natural source of antioxidant in food systems to prolong the shelf life of various products (Chong et al. 2015). The pectin polysaccharide from the mangosteen rind has higher antioxidant activities (225–253 DPPH inhibition activity). Mangosteen peel was reported to have a total phenolic content of 1.16 to 1.64 mg GAE/mL in ethyl acetate and methanol solvents. The authors also reported that the peel also has the antioxidant activity of 15.01 mM/mg TEAC equivalent. Suttirak and Manurakchinakorn (2012) in their review documented that the presence of phenolic acids and flavonoids in the mangosteen peel exerts superior antioxidant activities. Among different anthocyanins, pelargonidin 3-glucoside, cyanidin-3-sophoroside and cyanidin-3-glucoside were primarily isolated from the mangosteen peel. Zhou et al. also confirmed that mangosteen peel had significant antioxidant activities and the total phenolic content. They also reported that mangosteen peel is also a good source of epicatechin, its benzyl thioether, gallocatechin gallate, (epi)afzelechin and epicatechin gallate all from the family of proanthocyanidins which are powerful antioxidants. Zarena and Sankar also reported that supercritical carbon dioxide extract of xanthones had antioxidant capacity as observed from IC_{50} values of 41.8 ug/mL for DPPH inhibition, 21.5 ug/mL for lipid peroxidation and 30.0 and 23.1 ug/mL for hydroxyl radical specific and non-specific sites. They also confirmed that mangosteen peel is a rich source of α-mangostin, 3-isomangostin, mangostanol, 8-deoxygartanin, 9-hydroxycalaba xanthone, gartanine and garcinone E. Mangosteen peel and rind are a major source of protocatechuic acid or phenolic acid. Mangosteen peel had TPC and free phenolic acid content of 70.2 and 218.1 g GAE/kg and 18.7 and 5.5%, respectively (Zadernowski et al. 2009). Most predominant phenolic acids in the peel and rind of mangosteen fruit are derivatives of hydroxybenzoic acid which includes m- and p-hydroxybenzoic acid, protocatechuic acid and vanillic acid along with caffeic, ferulic and p-coumaric acid, all derivatives of hydroxycinnamic acid. It also contains p-hydroxyphenylacetic and 3,4-dihydroxymandelic acid in its peel and rind (Zadernowski et al. 2009). In the study of Naczk et al. (2011), it was reported that the TPC of mangosteen peel and rind were 250 and 195 mg GAE/g of sample with higher antioxidant potential. Their study also reported TEAC values of 20.3 and 30.6 mM Trolox/g GAE and EC50 values of 6.2 and 3.8 ug GAE/assay.

5.7 Traditional Medical Use of Mangosteen

Fruit hull, bark and roots of *G. mangostana* are being utilized as a traditional medicine for the past 100 years in Southeast Asia to treat several medical ailments. In various parts of India, China and Thailand, dried powder of fruit hull is used as an antimicrobial agent as well as antiparasitic treatment to treat dysentery (Ji et al. 2007; Nakatani et al. 2002; Yu et al. 2007). It is also used to treat external wounds, chronic ulcers and suppurations. The pericarp has been widely used to treat dysentery and diarrhoea as a part of traditional Ayurvedic treatment. The medicinal properties of mangosteen possess a variety of medicinal properties like antiparasitic, antifungal, antibacterial, antimalarial, anti-inflammatory and anticancer activities. The pericarp of mangosteen is known to exhibit antibacterial activity against various pathogens like *Staphylococcus aureus*, *Staphylococcus epidermidis* and *Propionibacterium acnes* which are known to cause dermatological lesions. α-Mangostin has inhibitory action against some microbes like *P. acnes*, *S. epidermidis* and *S. aureus* along with having anti-inflammatory activity.

Mangosteen is known to possess strong anti-inflammatory properties especially the leaves and bark which can be further used to formulate an ointment to treat many skin disorders like hyperkeratosis, eczema and psoriasis (Sakagami et al. 2005). The decoction prepared from its rind is fed to treat diarrhoea, gonorrhoea, cystitis and gleet. The decoction can also be externally applied as an astringent lotion (Farnsworth and Bunyapraphatsara 1992; Sato et al. 2004). The astringency of mangosteen is also used to control dehydration and excessive loss of essential nutrients from the gastrointestinal tract during diarrhoea. The fruit hulls of *G. mangostana* are used to treat skin infections, wounds and diarrhoea in the Thai traditional medicine system (Jung et al. 2006). In some parts of Malaysia and Philippines, a special tea from the rind and decoction from the bark and leaves are used as a febrifuge along with treating patients suffering from dysentery, diarrhoea and various urinary problems. The root extract is known to be advantageous for women when administered during menstrual disorders. A study conducted by Moongkarndi et al. (2004) proclaimed that an extract from the bark of mangosteen known as 'amibiasine' is known to cure amoebic dysentery. Medicinal applications of *G. mangostana* are also found in the Caribbean and Latin America, where a tonic tea prepared from the mangosteen fruit is widely used for fatigue and low energy states. A similar tea is also used in Brazil as a digestive aid, whereas in Venezuela, extracts of fruit rind are used to treat various skin infections.

5.7.1 Mangosteen as a Health Food Supplement

The antioxidant properties of extracts of various parts of mangosteen using the estimation assays described in the section 'Methods for Estimation of Antioxidant Properties' show that mangosteen is a potential source of antioxidants and can be utilized as a functional ingredient in various foods and health food supplementation. A considerable decline in the food supplements in the market during 2004 enhanced the growth of botanicals in the unfolding of a new era of health products known as 'superfruits'. Many marketing companies developed a large niche market at a global level for liquid botanical supplements. Such products are being sold in the retail market in the form of traditional beverages. The so-called liquid botanical supplements, like combinations of several exotic fruits, are being used as convenience products and are known to have health benefits. This approach was the result of the former trend in the global market which was associated with the antioxidant supplements such as grape seed, green tea, black tea, polyphenol-rich extracts, juices or concentrates derived from such plants. After reviewing a good worldwide success of many western and exotic fruits such as blue and black currant berries as herbal and botanical supplements, many liquid supplements derived from noni, goji and mangosteen juice were in huge demand in the early years of the twenty-first century.

Mangosteen being termed as a 'novel superfruit', food processing industries are processing the juice of mangosteen and its consumption and sales have increased progressively around the world over the last decade. At present, mangosteen juice surpasses the sales of green tea in the US market among the food supplement segment as companies are using the promotion strategies as health benefits of the fruit to take over the market (Obolskiy et al. 2009). Based on the applications and usage of the mangosteen, the market segment of mangosteen includes food and beverages, nutraceuticals, pharmaceuticals and cosmetics, and among these, nutraceuticals segment reached the remarkable peak in comparison to other segments. The key players for the mangosteen-based supplements in the global market are DBC, LLC, Nature's Sunshine Products, Inc., Royalty Health, Genesis Today, Lakewood Juice Company, Vemma, Mangosteen Dietary Supplements and others. The main products available in the market are mangosteen fruit powder, mangosteen fruit extract capsules, mangosteen pericarp-based capsules, mangosteen pericarp extract, mangosteen mixed fruit juice and mangosteen-based green tea, among others. The market of these products is mainly found in Europe, USA, Japan, Canada, Mexico, Australia and Asia.

Due to the largest growing market of the mangosteen-based health supplements, false claims and misleading advertisements are hitting high in the market without the knowledge of their pharmacologically active ingredients, human health effects and safety of consuming such products, as most of the manufacturers are citing the data from low-quality predatory journals to expand the sales and promote their products (Lobb 2012). The manufactures of the mangosteen-based health supplements should also carry the research in vitro and in vivo activities of the compounds, their clinical trials, besides focusing only on their safety aspects. At present, guidelines are under preparation for the recommended daily dose of the mangosteen compounds or extracts related to the health benefits they exert and justification of such claims.

5.8 Concluding Remarks

Mangosteen fruit is named as the queen of tropical fruits due to its attractive look and taste. It is consumed as fresh and processed worldwide, as they have amazing molecules whose properties have a great potential benefit to human health. Mangosteen is one of the essential sources of natural antioxidants. The bioactive components are mainly present in the peel, pulp and juice of the tropical fruit. Peel is an important source of natural antioxidants which is also recommended as a potent source of antioxidant for the stabilization of the food systems. Despite being a natural and potential source of antioxidants, mangosteen also exhibits several antifungal, antibacterial and anti-inflammatory properties too. However, further research is required to explore the potentiality and applications of this wonder fruit in processed food products to study the fate of the bioactive compounds during processing.

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6 Avocado

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Abstract

Avocado (*Persea americana* Mill.) is an exclusive tropical and subtropical fruit which is increasingly gaining acceptance worldwide. It is called by different names in different regions of the world. Avocado is considered to be the sixth important subtropical crop which is cultivated in 50 different countries in the world with Mexico and Central America as the leading producers. There are different varieties of avocado, but variety Hass has proved to be an excellent source of nutrients and storage stability due to the presence of thick bumpy skin in comparison to other varieties. Avocado leaves, seeds, and fruits are already exploited in American continent and to some extent in parts of Europe and Australia. Its unique bioactive constituents such as phytochemicals, phytosterol, vitamins, minerals, and fiber are present in fruit, seeds, leaves, and skin. The leaf of the plant contains antioxidants and acts as free radical scavengers and thus are commonly used as traditional medicines. The peel and seeds of avocado are also a rich source of phenolic compounds in addition to starch and fiber. The seeds are rich source of carbohydrates like hemicelluloses, fibers, and starch. The residues of avocado contain essential oils which contain a considerable amount of polyphenolic compounds such as proanthocyanidins and catechins and quercetin glycosides which are of economic importance. The avocado oil can also be used as a substitute of replacing olive oil due to its excellent health benefits. Due to the presence of numerous phytochemicals and unsaturated and monounsaturated fatty acids, it is considered to be the best fruit having health benefits. Besides being used as such, it is used as a vegetable in combination with other vegetables like onion and lettuce in the United States, Mexico, and Cuba. In this

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chapter, we endeavored to bring all categories of available information about the avocado fruit, seed, skin, and oil including its production, proximate composition, bioactive constituents, and its health benefits.

Keywords

Avocado · Essential oil · Phytochemicals · Antioxidants · Health benefits

6.1 Botanical Name: *Persea americana* (Lauraceae)

6.1.1 Common Name

Avocado has been recognized by numerous names in different regions of the world where this fruit is consumed. The first name of avocado was alligator pear which was then given by Americans. This fruit is known by the name aguacate by some regions, and other regions pronounce it as ahuacate. The people of Peru and Chile named it as palta. A tribe in Mexico where Otomi language is spoken named it as nttzani. In the state of Michoacan, the people call it as cupanda. In some parts of Mexico, it is named as ahuacatl, which has two meanings, *Persea americana* fruit and "testicle," and others call it as ahuatl, which means oak tree. In north Guatemala it is called as Aguacatlan. The name Pahua is also given to some varieties having thick skin in some regions of Mexico. Near the Atlantic coast, they called it by the name of cucate, and Zapotec tribe called it as Yasu, Yashu, and isu. People in Guatemala call it as okh. In France, it is called by the name avocate or poire d'avocat. In Spain, it is called as avigato or avocado. Collins in his bulletin, which was published in 1905, has listed 43 different names given to avocado which resemble the above given names with some exceptions. The most famous name accepted by the world today is avocado (Wilson Popenoe et al. 1997).

6.2 Introduction

Avocado, which is a dicotyledonous plant, belongs to the order *Laurales* and family *Lauraceae*. Gaertner classified it as *Persea gratissima* and Miller classified it as *Persea americana*. Approximately 2200 subspecies were developed by *Persea americana* due to geographical isolation (Fajardo et al. 2005). It is considered as God's greatest gift to human beings (Popenoe 1935). Avocado tree grows to a height of 10–12 m with a ligneous trunk and achieves a diameter of about 80 cm to 1 m when 25–30 years of age (Lidia Dorantes 2004). It takes approximately 20 years for an avocado tree to produce seeds. The fruit does not ripe on trees so mature fruit is stored for several months on trees. These fruits are then harvested manually with special shears to reach the tall trees. Harvested fruits are kept in nylon bags for further maturation (Bleinroth and Castro 1992).

Avocado pulp is rich in proteins and fats approximately 3 and 40%, respectively, and contains very less amount of carbohydrates. The fat of avocado resembles olive oil and is of economic importance to cosmetic industry. The energy valve of avocado is high (245 cal /100 g) besides containing a good amount of vitamins and minerals and contains almost all amino acids. This fruit is a very excellent source of minerals like potassium, copper, and iron.

Avocado fruit is regarded as the most nutritious fruit, and its consumption results in the reduction of weight as it contains high amount of fiber, with a desirable amount of monounsaturated fatty acids, proteins, minerals, vitamins, and antioxidants (Cowan and Wolstenholme 2003). Thus several agencies have recommended its consumption on a regular basis. The Nutrition Labeling and Education Act (NLEA) has recommended a consumption of approximately 30 g avocado per day, while the National Health and Nutrition Examination Survey (NHANES) 2001–2006 suggested a 68 g consumption to meet the basic requirements of vitamins and minerals (Fulgoni et al. 2010a, b). Besides a rich source of nutrients, avocados also contain oil (5–40%) the percentage of which varies according to various environmental factors like variety, season, and degree of ripeness. Avocadoes are considered to be ready for market as they need no processing, taste enhancers, and any kind of preservatives for preservation. As the fruit is covered by a thick skin, there is no need for packing of the fruit as it automatically resists the entry of insects. Avocado has smooth textured greenish, purplish, or blackish colored skin. Skin and seeds account for 33% of total weight of the fruit (USDA 2011). Avocado in combination with onion, lettuce, or with other vegetables is used as salad in the United States. In Mexico and Cuba soups added with the avocado fruits are highly liked by consumers, and in some countries like Brazil, it is used as a dessert, and nowadays it is a precious marketable fruit crop around the globe (Bill et al. 2014).

Avocado is considered as a key tropical fruit which is a rich source of proteins; fat-soluble vitamins like vitamins A, D, and E; and other vitamins like B complex. Being a rich source of oil, it is used commercially for oil production like olive oil (Bleinroth and Castro 1992). The lipid fraction of avocado is high in omega 3 fatty acids, phytosterols, tocopherols, and squalenes which find its use in pharmaceutical and cosmetic industries (Santos 2014).

6.2.1 History

Spanish explorers were the first to discover avocadoes. Martín Fernández de Enciso in 1470–1528 mentioned in his book about avocados. He called the fruit as aguacate. These then spread to Mexico. The avocados may have originated from Southern Mexico as these have been part of Mexican diet from time immemorial. Evidences of presence of avocado in central Mexican diet before 10,000 years have been found by archaeologists. Researchers found that avocados were cultivated about 5000 years ago and before this these were consumed as wild fruit (Popenoe and Zentmyer 1997).

Bernabe Cobo in 1653 described about the three main types of avocado, i.e., Guatemalan, Mexican, and West Indian. In the Philippines and Dutch East Indies, avocados were grown in 1750 and in Mauritius in 1780, and by that time different people suggested different names for avocado. George Washington in 1751 coined agovago pears for avocado. In 1696 Sir Hans Sloane, an Irish naturalist, mentioned the plant in his catalogue of Jamaican plants and coined the word avocado for it. The actual cultivation of avocado was done by Peru before the Europeans arrived, and these were then carried to the West Indies and to other subtropical and tropical areas where the environment was suitable for its growth and cultivation. The distribution then spread to Hawaii in 1825 and then to Singapore in 1830. Later a horticulturist, "Henry Perrine", planted avocados in Florida in 1833 (Affleck 1997). In the United States, avocado was introduced by Judge R. B Ord of Santa Barbara in 1871. Commercially these were cultivated by growers in the early 1900s with some 25 improved varieties. Among these varieties Fuerte gained economic importance, and these varieties were packed and shipped to California. In 1930, another variety came in existence which was named Hass after the name Rudolph Hass. Due its indigenous taste, people loved to consume Hass more and replaced Fuertes in California as a leading variety in 1970 (Macías 2010).

6.2.2 Production

Avocado is considered to be the sixth important subtropical crop and is cultivated in 50 different countries in the world (Demirkol 1995). It has been estimated that avocado worth $157 million were imported to the United States in the year 2004. Chile alone imported approximately 50% of avocado with shipments valued at $80.4 million followed by Mexico, which supplied 38.2% of fresh avocado worth $75.5 million. There is an increase in the prices of avocado due to increasing demand (FAO 2004).

Before 2003 Mexico was considered as the leading country for exports of avocado, but 97% of the fruit was utilized for domestic use in 2004 which contributed to less exports of this fruit. After 2004 onward agriculture has become the most dynamic sector due to which the production of fruits and vegetables has increased. Exports of fruits and vegetables in Mexico grew by 9.6% on an annual average (Macías 2010; Cruz et al. 2012), and once again Mexico became the leading country for production of avocado and exported 806,367(t) of fruit to different countries followed by Indonesia, the United States, Columbia, and Brazil (FAOSTAT 2020; FAO 2004) (Table 6.1). Besides being the highest producer, avocado from Brazil does not meet the quality standards and was not accepted by the international market (Van Zyl and Ferreira 1995). On the basis of quality standards, South African avocado was considered to be of superior quality, and South Africa was the leading exporter till 2010 (Witney 2002) followed by Spain, Mexico, Chile, and Peru (Naamani 2011). North and Central America contributed to 80% of total production of avocado in 2011, while 20% of the production was supplied by rest of the world. The production of avocado reached to 4.4 million tons which showed an increase of 20% than the production in 2007. According to FAO 2013, Mexico produces 25% of the world production, followed by Chile, which

Table 6.1 Top 20 avocado-producing countries (2018)

Rank	Country	Production in tons (2018)
1	Mexico	2,184,663
2	Dominican Republic	644,306
3	Peru	504,517
4	Indonesia	410,094
5	Colombia	326,666
6	Brazil	235,788
7	Kenya	233,933
8	United States	168,528
9	Venezuela	139,685
10	Israel	131,720
11	China	128,743
12	South Africa	127,568
13	Guatemala	124,931
14	Chile	124,506
15	Malawi	92,239
16	Haiti	90,699
17	Spain	89,592
18	Cameroon	75,221
19	Democratic Republic of the Congo	65,773
20	Australia	63,486

Source: FAOSTAT (2020)

produces 8.5% alone. This increase in productivity is because of the less trade barriers, increase in the postharvest techniques, increased incentives, publicity, and utilization of land for the production (Almeida and Sampaio 2013). The export of avocado from Mexico increased from 25 to 34% from 2013 to 2016 which accounted for 1,889,354 tons of produce. Dominican Republic produces 10.8% which account for 601,349 tons, while Peru and Colombia produced 455,394 and 309,431 tons, respectively. In European market Israel, Spain, Italy, and the United States are also important producers. The major producers of avocado in 2017 was Mexico, Dominican Republic, Peru, and Colombia (Zang Jing 2017).

The world's 97% avocado fruit is exported to the European Union. Generally, Hass and Fluert with a small amount of Pinkerton are exported. The biggest market potential for avocados is in France, Germany, and the United Kingdom (Witney 2002).

The production of avocado is greatly influenced by some external factors like weather, irrigation, and insect pest control in every country from where large exports are expected. Since it is a good source of vitamins, minerals, and other constituents, it gained a lot of international recognition. Based on the health benefits, its production is increasing at a very significant rate in Asian countries also. China imported 32,100 tons of avocados in the year 2017 as compared to 2016 imports (25,128 tons) which showed an increase of 1000 tons in 1 year. The main avocado exporters to

China are countries like Peru, Mexico, and Chile. Peru alone exported avocado worth 150 million pounds in 2017 which is twice the quantity exported in 2016 (Fresh Plaza 2018). Besides the countries like China, Korea and Vietnam also supplies avocado to the international market. About 4.5 million avocados are harvested commercially worldwide which is worth 2.1 billion dollars, and the number one importer is the United States followed by the Netherlands (Zang Jing 2017). The export and import of the varieties depend on the quality parameters of the fruit and its shelf stability. Hass avocados proved to be excellent on the basis of shelf life and storage qualities due to the presence of thick bumpy skin as compared to other varieties (Fresh Plaza 2018).

In India, avocado cultivation on a small scale is done in Kerala, Karnataka, Tamil Nadu, and some parts of Maharashtra. It is also grown on the hill slops or higher elevations of Sikkim to prevent soil erosion and also withstand waterlogging and poor drainage conditions. Its cultivation is restricted toward the north because of the adverse dry and hot winds due to which it does not survive in such conditions. Although it is not a commercial fruit today in India, it is a well-thought-out that this can be a gateway fruit to the future of India due to its well-known health benefits and shelf stability and in future may help to reduce the problem of malnutrition (Dreze and Jean 2001).

6.2.3 Botanical Description

Avocados belong to the same genus *Persea* and family laurel (Lauraceae) to which cinnamon tree, sassafras, and camphor belongs (Bergh and Ellstrand 1986). Avocados have originated first in Central America and Mexico approximately 1200 years ago (Yahia and Woolf 2011), and it is the only edible fruit with a high commercial value which makes it vital fruit of Lauraceae family. There are more than 150 species in which most of the species (approximately 70%) grow in warm regions of America (Ding et al. 2007; Ranade and Thiagarajan 2015). The botanical name of avocado is *Persea americana* Mill. which has been divided into three ecological races (Cowan and Wolstenholme 2016):

1. West Indian race
2. Mexican race
3. Guatemalan race

All the three races differ in their fruit maturity and percentage of oil (Biale and Young 1971).

(1) The West Indian race constitutes fruits of variable shapes with leathery and glossy skin which contains low oil content. *P. americana* Mill. var. *americana (P. gratissima* Gaertn.) are included in this type of race. These kinds of trees are sensitive to frost and get damaged by low temperatures below −1 to -2 °C (Joubert and Bredell 1982).

(2) The Mexican race is thought to be originated from Mexico and Central America and bears fruits small in size, with a thin and smooth skin. The color of skin and flesh is green. These fruits are usually elongated and contain high oil content. This race includes *P. americana* Mill. var. *drymifolia* Blake *(P. drymifolia* which is cold tolerant. The trees of this race withstand a temperature of as low as −4 °C (Joubert and Bredell 1982; Yahia and Woolf 2011).
(3) Guatemalan race is subtropical with large fruits with high oil content. *P. nubigena* var. *guatemalensis* L. Wms. is included in this race. The fruits of this race are round in shape with a thick skin (Bergh and Lahav 1996). *Persea drymifolia* and *Persea americana* can be easily distinguished from each other as leaves of *P. drymifolia* have an aromatic odor resembling that with anise or sassafras and *P . americana* lack this kind of odor. The leaves are also different as the leaves of *P. drymifolia* are juvenile and glaucous than *P. americana.* The fruits of *P. drymifolia* have thin membranous skin than the fruits of *P. americana* which has a leathery or thick skin (Yahia and Woolf 2011).

Avocado tree is evergreen and leafy and reaches to a height of up to 20 m (Litz et al. 2007); however during commercial cultivation, it is grown up to a height of not more than 5 m to facilitate harvesting, pruning, and other fertilization practices. Usually the seedlings grow short, but some of the seedlings grow erect or slender also. They reach up to a height of only 30 feet when grown on shallow soils and 60 feet on deep moist clay loams. These trees on maturation develop dense foliage with millions of flowers, but few of them get transformed into fruits (Sagarpa 2011). The male and female flowers are present on the same trees, and these flowers open at different times. Female flowers open first and get closed and then the male flowers open thus avoiding self-fertilization. The fruit-bearing trees produce up to thousand avocados in a year (Litz et al. 2007; SIAP 2015).

The leaves of avocado plant are alternately positioned, dark green in color with a gloss and having yellow veins. The average life of a leaf is 2–3 years. The flowering appears from the month of January to March after which small terminal blooms yellow to green in color appear. Each panicle produces one to three fruits. The followers either accept pollen in the morning and shed it in the following afternoon or accept the pollen in the afternoon and shed it the following morning. Pollination occurs by cross-pollination and bees and flies get attracted. The fruits at the time of harvest are hard in texture but soften later on. The off-season fruit is not harvested with the main fruit, but it is left on the tree for maturation. But if allowed to overmature, seeds sprout out causing internal molds and breakdown of the flesh. Avocados are second to olives having high content of monosaturates. The pear-shaped mature fruits are light to dark green in color with rough skin and with yellow-colored inner flesh. The average weight of the fruit varies from 150 to 350 g depending upon the variety (Rodríguez and Sánchez 2005). In some cultivars color changes from green to black or purple with the advancement of maturity. Thus the size, shape, color, and weight of the fruit vary according to the cultivar used some of which are given below:

1. *Fuerte*: The fruit is pear shaped small to medium in size with rough skin having yellow dots on it. The oil content ranges between 12 and 17%.
2. *Hass*: The fruit is ovoid or pear shaped with dark purple rough skin and turns black when ripe. It is a midseason fruit with excellent taste and flavor. The production of Hass avocado is higher than other avocados.
3. *Ryan*: The tree bearing this kind of fruit is large which bears medium-sized, pear-shaped fruits with rough skin. It is a late season fruit.
4. *Pinkerton*: This fruit is round in shape with a pear-shaped neck and leathery flesh, thicker than Hass and Fuerte. The seeds are small and tend to separate easily from the flesh.
5. *Reed*: This fruit is medium to large in size with a slightly rough skin, flesh cream in color with a strong nutty flavor. The seeds are small in size and tight adhering to the seed coat. It is considered to be of excellent quality and is very sensitive to cold.
6. *Edranol*: It is a pear-shaped fruit of medium size and olive green in color. The skin is slightly rough, leathery with nutty flavor. The seeds contain oil content of 15–18% and the fruit is disease resistant.
7. *Bacon*: The fruit is round in shape, small to medium in size with a smooth skin, slight greenish in color (Yahia and Woolf 2011).

The species *Persea americana* can be classified as:

Kingdom: Plantae
Division: Magnoliophyta
Class: Magnoliopsida
Order: Laurales
Family: Lauraceae
Genre: *Persea*
Species: *Persea americana* Mill (Teliz-Ortíz et al. 2000)

6.2.4 Nutritional Composition

Nowadays avocado is considered to be a nutritious fruit because of the high amount of phytochemicals present in it (Araújo et al. 2018). It is consumed as salad, puree, seasoned with salt and other condiments, sprinkled with vinegar or used for the preparation of various dishes (Koller 1992). In some parts of Brazil, the ripe fruit is dressed with honey, liquors, and sugar to increase its palatability and sensory characteristics (Luiz et al. 2007). In addition to it, avocado contains a considerable amount of phytosterol in its lipid fraction particularly in the form of β- sitosterol which is found to be useful in reducing the levels of LDL cholesterol and total cholesterol (Lottenberg 2002; Salgado 2008; Santos 2014). Beta-Sitosterol improves immunity and helps fight certain diseases by suppressing carcinogenesis. It is also found helpful in reducing the chances of cancer, HIV, and other diseases (Bouic 2002). The proliferation of lymphocytes is also influenced by this compound which inactivates the invading microorganisms (Bouic 1996). It has also been observed that β-sitosterol reduces compulsive eating and accumulation of fat in abdominal regions (SENAI 2006; Murta 2013). Phytosterol inhibits absorption of intestinal cholesterol and hence reduces the synthesis of hepatic cholesterol. It actually affects the deposition of total and LDL cholesterols by replacing saturated fats by unsaturated fats (Salgado 2008; Brufau 2008).

6.3 Antioxidant Properties

Antioxidants are the substances which inhibit the oxidation of other substances as the body lacks a definite antioxidative defense in a system. The body always needs exogenous antioxidants on exposure to excessive free radicals. Nowadays natural antioxidants are always preferred than the artificial ones due to the side effects of synthetic antioxidants (Shahidi and Chandrasekara 2015; Lobo et al. 2010). A lot of research have been done on the antioxidant activity of tree leaves which showed that there are certain compounds like flavanoids present in the plant system which act as the free radical scavengers and are commonly used as traditional medicine (Chen et al. 2017).

It has been observed that 80% of the society in the world use traditional medicines coming from plants as healthcare effort (Ekor 2014). Plant products like fruits, vegetables, and spices contain natural biochemical compounds which have health benefits, and avocado is considered as a good source of antioxidants that can be used as a traditional medicine (Putri et al. 2013; Kurniawan 2014). It is considered to be vary nutritious and having preservative properties also (Gomez et al. 2014; Drehe and Davenport 2013). Avocado fruit contains a number of bioactive components like carotenoids, phenolic compounds, and vitamins E and C which are very beneficial to human beings. The fruit of avocado being big in size produces a large amount of peel and seeds which were considered as a waste and nuisance for society, but both of these (seeds and peel) contain a lot of phytochemicals which have health benefits that help to reduce the inflammatory diseases (Dabas et al. 2013). The leaf of avocado is a potential source of saponins, alkaloids, steroids, flavanoids, and tannins (Putri et al. 2013) and possesses diuretic properties, thus is widely used as pharmaceutical ingredient as well as a beverage in folk medicine (Wright 2007). The presence of the phytochemical compounds in avocado helps to prevent oxidative stress also (Owolabi 2010).

6.3.1 Peel and Seeds

Worldwide different varieties of avocado like Hass and Fuerte are cultivated (Rodríguez-Carpena et al. 2011). These two varieties are mostly consumed and their by-products like seeds and peel (18–23%) are processed in order to reduce environmental pollution and to extract the phytochemicals present in them (Wang et al. 2012; Melo et al. 2015; Tehranifar et al. 2011). Chemical composition of

Table 6.2 Chemical composition of avocado seed and peel of different cultivars (dry basis, % w/w). Cultivar Hass

Fruit part	Moisture	Minerals	Lipids	Fibers	Proteins	Carbohydrates	References
Seed	14.55	2.81	3.32	3.97	0.14	–	Daiuto et al. (2011)
Peel	9.87	2.15	2.18	1.29	0.17	–	
Seed	7.66	3.85	5.52	3.98	3.44	79.54	Bressani et al. (2009)
Peel	14.5	6.05	9.14	50.65	8.28	62.03	
Seed	54.45a	1.29	14.7	–	2.19	–	Vinha et al. (2013)
Peel	69.13	1.5	2.2	–	1.91	–	

Source: Araújo et al. (2018)

avocado seed and peel of different cultivars is shown in Table 6.2. Avocado seeds serve as a rich source of 2.3–5.7% phenolic compounds in addition to starch and fiber and also contain some other non-nitrogenous substances ranging from 5.1 to 13% (Salgado 2008).

The composition of seeds and peel varies from cultivar to cultivar as different factors influence its composition during the developmental stages. Seeds are a good source of carbohydrates like hemicelluloses, fibers, and starch (Araújo et al. 2018). Avocado residues also contain essential oils and fibers. A complex mixture of polyphenolic compounds such as proanthocyanidins and catechins are also found in the residues of avocado. There are certain other compounds like quercetin glycosides and proanthocyanidins which are also of economic importance (Soong and Barlow 2004; López-Cobo et al. 2016).

The seeds of avocado are also rich source of starch approximately 30% (Domınguez et al. 2014; Lacerda et al. 2015). The starch, which is a biopolymer, serves as an important reserve for the polysaccharide and is composed of amylose and amylopectin. The ratio between the amylose and amylopectin varies according to structure, size, morphology, source, developmental stage, and other environmental conditions which makes the starch molecules a variable polysaccharide for industrial applications like paper, textile, and food (Chel-Guerrero et al. 2016a, b; Henríquez et al. 2008; Lacerda et al. 2014). This starch can also be utilized as a source for the production of bioethanol after a physicochemical pretreatment (Aditiya et al. 2016; Bahry et al. 2017). There are several latest technologies which are environment-friendly like pulse electric field, microwave processing, ohmic heating, and supercritical fluid extraction that can be employed to extract different compounds which reduce the negative effects on the bioactivity and structural modification of the active components present in avocado (Carciochi et al. 2017; Galanakis 2012; Wong-Paz et al. 2017).

6.3.2 Antioxidant Properties of Pulp

The pulp content of avocado fruit varies (52–81%) from variety to variety and also depends upon the size of the fruit (Tango 2004). Upon moisture removal the content of lipids increases, while the carbohydrates decrease which in turn increases the dry matter content of the product. Thus, it falls among the fruits having higher lipid content (Tremocoldi 2011). The lipid content of the fruit reaches to 25% (Hierro et al. 1992). The pulp of avocado is considered to be rich source of both soluble and insoluble fiber in the range of 30–70%, respectively. The pulp is also rich in protein and sugars like D-mannoheptulose, sucrose, and seven-carbon carbohydrates (Cowan and Wolstenholme 2016; Drehe and Davenport 2013). It also contained a considerable amount of pigments, phytoestrogens, polyphenols, and tannins (Zafar and Sidhu 2011). The moisture content ranges from 67 to 78%, carbohydrate 0.8–8.4%, fat content 12–24%, protein 1–3%, fiber content 1–3%, and energy values from 140 to 228 Kcal (Table 6.3) (Soares and ITO 2000; Duarte et al. 2016; Rodríguez-Carpena et al. 2011).

Avocado pulp is a good source of mineral like potassium, phosphorus, magnesium, calcium, and sodium and also other minor elements like zinc and iron which account for less than 1 mg per gm of fresh fruit weight. Due to the high amount of potassium and low-sodium content, it is considered as a beneficial fruit for the persons who need low-sodium diets (Cowan and Wolstenholme 2016; Zafar and Sidhu 2011). The avocado fruit is also rich in vitamins like β-carotene, retinol, vitamin E, vitamin C, and other B complex vitamins like thiamine, riboflavin, niacin, pyridoxine, and folic acid which are very important for overall health and well-being. (Alvarez et al. 2012) (Table 6.3). It is also high in glutathione, which is considered a strong antioxidant against different kinds of carcinogens (Wang et al. 2012).

6.3.3 Antioxidant Properties of Avocado Oil

Avocado pulp is considered as a rich source of lipids (5–35%), and a major portion of which contains 60–84% unsaturated fatty acids. Since ancient times avocado has been considered as a fruit having therapeutic uses. The oil extracted has many beneficial effects on human health and is nowadays used as a dietary supplement for human beings (Borges and Melo 2011). The percentage of oil depends on the moisture content of pulp and the core and shell percentage of fruit. The fruit with lower percentage of shell and core bears more oil due to higher pulp yield (Tango 2004). The percentage of oil also depends on the method of extraction which in turn affects the chlorophyll content, carotenoid content, phenolic compounds, vitamin E content, and also the antioxidant activity of the oils (Flores et al. 2019). Several processes have been suggested for the extraction of oil. The oil can be extracted by:

(i) Drying the pulp at different temperatures
(ii) By cold pressing

Table 6.3 Avocado pulp composition

Nutrient/phytochemical	Unit	Value per 100 g	1 fruit (136 g)	1 serving (30 g)
Proximate composition				
Water	(g)	72.3	98.4	21.7
Energy	(kcal)	167	227	50
Energy (insoluble fiber adjusted)	(kcal)	148	201	44
Protein	(g)	1.96	2.67	0.59
Total lipid (fat)	(g)	15.4	21	4.62
Ash	(g)	1.66	2.26	0.5
Carbohydrate	(g)	8.64	11.8	2.59
Fiber	(g)	6.8	9.2	2
Sugars	(g)	0.3	0.41	0.09
Starch	(g)	0.11	0.15	0.03
Minerals				
Calcium	(mg)	13	18	4
Iron	(mg)	0.61	0.83	0.18
Magnesium	(mg)	29	39	9
Phosphorus	(mg)	54	73	16
Potassium	(mg)	507	690	152
Sodium	(mg)	8	11	2
Zinc	(mg)	0.68	0.92	
Copper	(mg)	0.17	0.23	0.05
Manganese	(mg)	0.15	0.2 0	0.05
Vitamins and phytochemicals				
Vitamin C	(mg)	8.8	12	2.6
Thiamine	(mg)	0.08	0.1	0.02
Riboflavin	(mg)	0.14	0.19	0.04
Niacin	(mg)	1.91	2.6	0.57
Pantothenic acid	(mg)	1.46	2	0.44
Vitamin B6	(mg)	0.29	0.39	0.09
Folate food	(μg)	89	121	27
Choline total	(mg)	14.2	19.3	4.3
Betaine	(mg)	0.7	1	0.2
Vitamin B12	(μg)	0	0	0
Vitamin A	(μg)	7	10	2
Carotene beta	(μg)	63	86	19
Carotene alpha	(μg)	24	33	7
Cryptoxanthin beta	(μg)	27	37	8
Lutein + zeaxanthin	(μg)	271	369	81
Vitamin E (alpha-tocopherol)	(mg)	1.97	2.68	0.59
Tocopherol beta	(mg)	0.04	0.05	0.01
Tocopherol gamma	(mg)	0.32	0.44	0.1
Tocopherol delta	(mg)	0.02	0.03	0.01
Vitamin k1 (phylloquinone)	(μg)	21	28.6	6.3

(continued)

Table 6.3 (continued)

Nutrient/phytochemical	Unit	Value per 100 g	1 fruit (136 g)	1 serving (30 g)
Lipids				
Fatty acids, total monounsaturated	(g)	9.8	13.3	2.94
Fatty acids, total saturated	(g)	2.13	2.9	0.64
Fatty acids, total polyunsaturated	(g)	1.82	2.47	0.55
Cholesterol	(mg)	0	0	0
Stigmasterol	(mg)	2	3	1
Campesterol	(mg)	5	7	2
Beta-sitosterol	(mg)	76	103	23

Source: USDA (2011), Araújo et al. (2018)

(iii) By using different solvents like petroleum ether, hexane in solvent extraction technique (Ortega et al. 2011), methanol, ethanol (Galvão et al. 2014)
(iv) By microwave heating (Santana et al. 2015)
(v) Enzymatic methods
(vi) Supercritical fluid extraction method (Corzzini et al. 2017)

The yield of the oil also depends upon the solvents used. A yield of 59% was obtained when solvent hexane was used and on using acetone yield decreased by 12% (Abreu and Pinto 2009). The extraction process of oil greatly affects composition of bioactive compounds and their preservation. The inactivation of enzymes like polyphenol oxidase and lipoxygenase is done at 60 °C which otherwise would directly inhibit the degradation of phenolic compounds (Luíz, 2007). This promotes the hydroxylation of monophenols to ortho-diphenols and then oxidation of them to quinine (Chisari et al. 2007). The inactivation of enzymes preserves the conversion of bioactive compounds like carotenoids, vitamin C, and anthocyanins which if catalyzed gets degraded to form unsaturated fatty acids and result in the formation of certain volatile compounds generating off-flavors (Paula 2007). Most of the phytochemicals which are present in fruit are retained by oil, including vitamins, minerals, β-sitosterol, and lecithin.

New technological processes are also employed nowadays like high-pressure technology which inhibits the enzymes and prevents browning and oxidation of the products (Toledo and Aguirre 2016; Zafar and Sidhu 2011). By applying these processes the oil extracted is of high quality and with high content of bioactive components and varying health benefits (Kmiecik et al. 1992). The oil of avocado is a rich source of monounsaturated fatty acids among which the oleic acid is found in the highest amount. Other fatty acids like arachidic acid, lignoceric acid, margaric acid, behenic acid, docosadienoic acid, gadolenic acid, myristic acid, and eicosanoic acid are found in smaller amounts also (Rueda et al. 2014).

The fatty acid composition of avocado is also influenced by the geographic regions, stage of maturity, and cultivar used (Tango 2004). In some countries the raw form of avocado oil is used by the pharmaceutical and cosmetic industries and is used in the treatment of skin diseases as its unsaponifiable fraction regenerates the epidermis layer. Avocado oil has high absorption power like perfumes and gets easily absorbed by the skin. It also forms easy emulsions which is ideal for manufacturing soaps (Tango 2004). The oil of avocado can be used as a substitute for replacing olive oil as it is a good alternative to reduce the cost of olive oils in the countries where both of these fruits are grown (Salgado 2008).

6.3.4 Antioxidants of Avocado Leaf

Several studies have shown that avocado leaf contains several phytochemicals like saponins, tannins, steroids, and flavanoids which are very useful in reducing the cholesterol metabolism (Visavadiya and Narisimhachariya 2009). The flavanoids also freeze the free radicals by donating hydrogen atoms and are useful in treating oxidative stress. As avocado leaves are high in flavanoid content, their consumption meets the daily requirement of flavanoids which is higher than any other component like vitamin E, vitamin C, and carotenoids (Pietta 2000). In some countries where the consumption of green tea, red wine, and unfiltered beer is low, the consumption of extracts of avocado leaf can meet the daily requirement of flavanoids. In addition to this, avocado leaves can be used as vegetable because it is a good source of phytochemicals like isorhamnetin, luteolin, apigenin, quercetin, and rutin and thus help to reduce the oxidative stress (Bolling et al. 2010; Owolabi 2010). Avocado leaves can also be used as medicine because of its diuretic properties (Wright 2007).

6.4 Avocado Processed Products

Avocado pulp can be processed to form a variety of products like paste, puree, and guacamole. The paste and puree can be stored for months and used when needed. Guacamole is a processed product that is seasoned with certain spices and condiments like onion, pepper, lemon, salt, and tomato. This is a main product from avocado which is being marketed in the United States (Daiuto et al. 2011). Avocado can be served as salad vegetables when halved and seasoned with mayonnaise, vinegar, lemon juice, and other dressings. The halves can be stuffed with seafood like shrimp, crabs, or the seasoned flesh and used as a filling in sandwiches (Schoeman and Manicom 2002).

6.5 Health Benefits

Avocado is regarded as an important fruit because of the presence of various bioactive components in its pulp, seeds, and oil which have several health benefits (Alvarez et al. 2012). It has been reported that if avocado is taken with regular balanced diet, it helps to lower cholesterol levels and reduces the chances of cardiovascular diseases (Patrícia et al. 2016). Long before, the extracts of avocado were used for the treatment of several diseases, and today also the extract is used effectively against fungal, microbial, larvicidal, and protozoal infections and also inhibits the lipid protein oxidation (Dabas et al. 2013; Jiménez-Arellanes et al. 2013; Yasir et al. 2010). Several researchers have reported that the bioactive compounds present in avocado have anticancerous activities (Lee et al. 2008). Bioactive components like xanthophylls are thought to reduce the effect of aging due to the protective DNA and antioxidant effects (Yong et al. 2009).

Avocado is a good source of dietary fiber and oil and also contains a good quantity of moisture which helps in weight management (Wien et al. 2011). Research is being conducted to see the possible effects of lutein and zeaxanthin present in avocado to prevent certain diseases which are associated with the possible deterioration of joint cartilage causing osteoporosis, and consumption of avocado on regular basis reduces the chances of eye dysfunction (Wang et al. 2007; Johnson et al. 2010). A mixture of avocado and soy unsaponifiables in the ratio of 1: 2 is thought to be anti-inflammatory with analgesic activities (Dinubile 2010; Lipiello et al. 2008); (Au et al. 2007; Henroitin et al. 2006; Berenbaum 2004; Blotman et al. 1997). The presence of MUFA 185 μg and lutein/zeaxanthin in fruit halves helps to improve the absorption of carotenoids from other fruits and vegetables and also helps to protect the skin from ultraviolet radiations (Roberts et al. 2009; Unlu et al. 2005). Its extract when applied on the skin helps to reduce skin aging and wound healing (Nayak et al. 2008; Rosenblat et al. 2011).

Studies have also shown that xanthophylls of avocado extract act against *Helicobacter pylori* which in turn helps to reduce the chances of gastric ulcers (Castillo-Juarez et al. 2009). This is also effective against breast cancer and inhibits the proliferation of mammary cells (Thomson et al. 2007).

6.6 Conclusion

Avocado is full of nutrients like protein, fat, vitamins, and minerals and other bioactive components and if consumed with a balanced meal has several health benefits. It is a good source of MUFA as its oil contains a considerable amount of energy, 1.7Kcal/g. It is also found to be a very good fruit for heart patients as it is low in saturated fatty acids and high in unsaturated fatty acids like MUFA and PUFA and a potential source of dietary fiber which plays a key role in lowering the cholesterol. There are other components like potassium and lutein which help to control the oxidative stress. Since it is considered as a rich source of oil which is present in the pulp of avocado, processes like high-pressure technology, microwave extraction, and solvent extraction using different solvents are useful for the extraction of avocado oil. The seeds and peel are also a very good source of phytochemicals so their utilization is a primary concern of the industries. The avocado leaf is a potential source of saponins, alkaloids, steroids, flavanoids, and tannins, which are used as a medicine by various tribes. These leaves are widely used as pharmaceutical ingredient and also taken as tea in folk medicine because of the possible diuretic properties. These compounds also help to prevent oxidative stress. So, avocado leaves can be utilized as food due to strong antioxidant properties. Thus, a lot of functional food products like cookies, cakes, and bread could be made from avocado seed flour when incorporated with wheat flour.

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Mosambi (Sweet Lime)

7

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and Nairah Noor

Abstract

Mosambi (sweet lime) belonging to the family Rutaceae is a citrus fruit grown mostly in the Southeast Asia. Mosambi is popular in India and usually bears fruit within 5–7 years. It is a rich source of water-soluble vitamin, vitamin C, minerals and total polyphenols and has good antioxidant properties. Mosambi (sweet lime) possesses several health benefits as it aids digestion and helps in curing scurvy, diabetes, urinary disorder and skin problems. Mosambi is fibre-rich fruit with low-glycaemic index. The by-products derived from mosambi wastes can act as a source of nutraceuticals, and low-cost nutritional dietary supplements can be produced in pharmaceutical, nutraceutical and food industries. This chapter summarized the detailed description of antioxidant components and the health benefits of the mosambi.

Keywords

Mosambi · Antioxidant property · Polyphenols · Low-glycaemic index · Nutraceutical

7.1 Botanical Name, Common Name

Kingdom: Plantae
Genus: Citrus
Species: *C. limetta*
Family: Rutaceae
Botanical name: *Citrus lumia,Citrus limetta,* and *Citrus limettioides*

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Common names: Sweet limetta, Persian lime, sweet lemon, sweet lime and Mediterranean sweet lemon
Indian names: Mosambi

7.2 Introduction

7.2.1 History

Mosambi (sweet lime) is originated from the Mediterranean region and came to California from Mexico. In 1943, mosambi was named “Millsweet” when its cultivar grew at the San Gabriel Mission. Mosambi (sweet lime) is a hybrid between lemon and citron, which comes from the archipelago of Southeast Asia (Inglese and Sortino 2019). Among the sweet limes (C. *limettioides* Tan.), the lime of Palestine is the most widespread as it is derived from a cross between citron and sweet orange.

7.2.2 Production

India is the popular cultivator of mosambi (sweet lime) particularly in central India (Hodgson 1967). It is indigenous to Southeast Asia. The demand of production is increasing in developing *countries* like China, *India*, southern Japan, Vietnam, Malaysia, Indonesia and Thailand (Khan et al. 2016). The sweet lime tree may be found growing in equatorial region and usually bears fruit within 7 years. The fruit is available twice a year in India, i.e. in July–August and November –March. Lime fruit is produced worldwide with an annual production of about 17.35 million tonnes. The top producers of sweet lime are Mexico, India, China, Brazil, and Argentina, which constitute 61.32% of total production (FAOSTAT 2018).

7.2.3 Botanical Description

Mosambi belongs to the citrus family, despite having a sweeter taste. It is medium-sized, round/oval shape with a slightly flattened bottom, and moderately seedy. The smooth skin is yellow with a pale green tint, developing an orange hue on ripening. The flesh is somewhat firm and juicy, and its flavour is bland due to its very low acid content. Flowers are white in colour. They can reach up to 25 feet in height and grows in tropical and sub-tropical climates (Bhaumik et al. 2018). It is usually propagated by seed and at the age of 10–20 years peak production occurs. It is consumed more as fruit. It is widely consumed in the form of jams, drinks, pickles, sorbets, candies and snacks (Braddock 1995; Braddock and Cadwallader 1992). Furthermore, mosambi juice is a versatile fruit juice.

7.3 Antioxidant Properties

Mosambi is naturally rich in phytophenolics and vitamin C (Gorinstein et al. 2004). It contains a good amount of flavonoids, i.e. PMF (polymethoxylated flavones) and GF (glycosylated flavanones) which are located in the leaves, seeds and flowery portion (Imran et al. 2016). Phytophenolics are reported to possess health benefits because of their free radical scavenging and metal chelation activities which make them capable of inhibiting oxidation processes in food systems (Gundgaard et al. 2003; Taguri et al. 2004). The phytochemicals also play a role in disease preventions related to pro-carcinogene inhibition, DNA repair and inhibition of formation of N-nitrosamine (Shahidi 1997). Mosambi also provides a sufficient supply of vitamin C, pectin and potassium. Mosambi has strong antioxidant, antimicrobial and anti-inflammatory properties, and intake of sweet lime is associated with a decreased risk of cardiovascular diseases and certain forms of cancer. Furthermore, all the plant parts of mosambi are used as traditional medicine.

7.3.1 Peels

Mosambi peels are good source of pectin and fibre. They possess antidiabetic and antiobesity properties (Baker 1994; Riccardi et al. 2008). Mosambi peel is usually regarded as waste in fruit juice industry but is the main source of phenols mainly flavonoids, essential oils and pectin. Mosambi peel can be used as a source of pectin in jam and jelly. Moreover, mosambi peel has good antioxidant properties due to high content of flavonoids, which make it an important constituent in the preparation of value-added foods with added health benefits. Younis et al. (2015) reported the effects of mosambi peel powder on the functional and technological properties of papaya jam. Furthermore, oil extracted from mosambi peel has a strong aroma and can be used as a flavouring agent in various foods and beverages.

7.3.2 Seed

Citrus seeds represent substantial wastes of citrus-processing industry. The chemical industry uses to extract flavonoids and essential oils from seeds of mosambi. Citrus seed oil is an excellent source of magnesium, sodium, potassium, iron and calcium (El-Adawy et al. 1999). Lipids extracted from mosambi seeds contain essential fatty acids and lipid-soluble bioactive compounds like carotenoids, polyphenols and tocopherols (Malacrida et al. 2012). Aromatic oils can also be extracted from mosambi seeds, which possess nutraceutical properties such as antioxidant, anti-inflammatory and antimicrobial. Citric essential oils contain many important compounds such as terpenes, camphene, α-pinene, sabinene, β-pinene, α-terpinene, myrcene, p-cymene, d-limonene, linalool, etc. Among all d-limonene is the most plentiful compound in citus oil possessing nutraceutical properties.

7.3.3 Fruit Juice

The mosambi juice is a refreshing drink during summers with abundant supply of vitamin C and instant energy (Arias and Ramon-Laca 2005). The mosambi juice yield is less than half of the fruit weight. Mosambi juice is rich in water-soluble vitamins and minerals. It also contains folic acid that strengthens the bone and joints. It is loaded with antioxidants that boast the immune system and increase resistance to infections, particularly from cold. Fruit juice flushes out toxins from the body and thus neutralizes the harmful effects of junk eating, stress and pollution that most of us are exposed to. It contains limonenes that benefit our health.

7.3.4 Fruit

Mosambi is resourceful fruit with both a sweet and sour taste. Citrus fruits are generally composed of oxygenated compounds, terpenes and nonvolatile compounds such as waxes and pigments (Kondo et al. 2000). D-Limonene, being the abundant terpene, possesses antimicrobial activity against gram-positive bacteria and also increases the effectiveness of sodium benzoate. A limonene called d-limonene works as an antioxidant and anti-inflammatory and anticancerous agent.

7.3.5 Leaves

Mosambi leaves are reported to possess the antihypertensive property. Perez et al. (2010) reported leaf extract of Mosambi (*Citrus limetta* Risso) provokes the hypertensive effect of angiotensin II.

7.3.6 Waste

Large amounts of by-product waste are generated every year from the juice processing industry (Mantheym and Grohmann 2001). The main by-products of citrus industry are the seeds, peel and pulp, which collectively account for 40–60% of the raw material (Licandro and Odio 2002). These by-products are mainly regarded as citrus wastes which are rich in phytochemical and nutrients which can be regarded as bioactives. These bioactivess can be efficiently used as ingredient in making healthy food supplements, favouring agents in processing of food, preservatives and as components in pharmaceutical drugs (Middleton and Kandaswami 1994). Phytochemicals extracted from citrus waste are also exploited in cosmetic makings which include antifungal and antibacterial lotions and soaps, perfumes and toiletries. Furthermore, valuable by-products can be obtained from citrus fruits such as pectin, beverage, bases, marmalades, peel seasoning, molasses and purees. Mosambi peels are rich source of flavonoids that possess antioxidant activity, thereby inhibiting oxidation reactions in food systems (Taguri et al. 2004). Moreover, the citrus by-products are mainly used as feed for animal.

7.3.7 Antioxidant Properties of Its Products

Functional foods are gaining much attention of consumers as they possess the health benefits beyond basic nutrition and reduce the risk of diet-related diseases. Functional foods rich in antioxidants provide protective effects against various diseases like oxidative stress disease, diabetes mellitus, cancers, cardiovascular disease and atherosclerosis. The products prepared from the mosambi are rich in antioxidants and phytochemicals. A study reported by Imran et al. (2016) used antioxidant extract in cookies to improve its nutraceutical property. Also, mosambi peel powder was added in papaya jam which improved the functional and technological properties (Yonius et al. 2015). Moreover, antioxidants and phytophenols extracted from mosambi can be used to increase the nutraceutical value in various food formulations. Thus, identification of bioactive compounds from by-products of the citrus processing industry can be utilized in pharmaceutical and food industry.

7.4 Characterization of the Chemical Compound(s) and the Pathways Involved

Mosambi is a citrus fruit comprised of an ample quantity of phytochemicals which are responsible for the antioxidant activity. Also, citrus fruits contain valuable biologically active compounds such as oxyprenylated compounds and terpenes which have been known since last 12 responsible for antioxidant activity (Munakata et al. 2012). Terpenes are found in greater amounts than sesquiterpenes. The major chemical compounds found in mosambi are d-limonene, β-pinene, β-myrcene, α-pinene, β-bisabolol and α-terpineol levels. The other minor compounds found in mosambi are linalool, sabinene, bergamol, trans-α-bergamotene, β-bisabolene, α-terpineol, cis-geraniol, geranial Tr, isopinocarveol, citronellal, aromadendrene, nonane, epi-β-santalene, α-terpineol acetate, terpinen-4-ol, trans-sabinene hydrate, farnesol, camphene, undecanal, nonanal, α-bisabolol, myrcenil acetate, octyl ester, (Z) sabinene hydrate, 4-1 methylenil acetate, 1-cyclohexene-1-methanol, trans-nerolidol, cis-myrtanol, octal cyclopropane, aldehyde peril Tr, trans-β-santalol, β-farnesene, α-farnesene, isopropyl palmitate, β-santalene and camphor,

D-Limonene is the most abundant monocyclic terpene possessing antimicrobial, antioxidant and anticancerous activity. It is a main component in many citrus oils like lemon, mandarin and orange. Generally, D-limonene as a flavouring agent is recognized as safe (GRAS). The pathways involved in the biological activities of these phytochemicals are that, they act as primary antioxidants due to the ability to scavenge reactive oxygen species (ROS) and redox properties, provide proton to free radicals, decompose peroxides and prevent the decomposition of hydrogen peroxides into free radicals. These free radicals are responsible for many diseases, such as cardiovascular disease and cancer, and cause damage to cell through DNA mutations responsible for many diseases.

7.5 Health Benefits

Mosambi possesses remarkable nutritional value. The investigation of nutraceutical potential of mosambi will validate their future prospects for utilization as replacement of synthetic medicine. It is very low in fat. Few of the health benefits are given below.

7.5.1 Prevents Scurvy

Deficiency of vitamin C causes scurvy characterized by spongy and purplish gums, loose teeth, bulging eyes, dry and brownish skin, ulceration of the tongue and mouth and cracked lip. Mosambi is the richest source of vitamin C and can act as effective preventive major in curing scurvy.

7.5.2 Improves Digestion

Mosambi is a good source of phytochemicals (flavonoids) which have sweet fragrance. It speeds up digestion by facilitating the secretion of acids, bile and digestive juice. It flushes out the toxins from the body by neutralizing the acidic digestive juices. Therefore, it is often recommended to people suffering from digestive and gastrointestinal problems. Sweet lime being rich source of potassium helps in controlling diarrhoea, nausea, vomiting, dysentery, loose motions and bloody amoebic dysentery. Moreover, it contains a lot of fibre which regulates digestion, keeps the bowl movement healthy and regulates constipation. Furthermore, d-limonene, the important component of mosambi, has found to be effective in palliating gastrooesophageal reflux disorder (Wilkins 2002).

7.5.3 Immunity Booster

Mosambi is a powerhouse of antioxidants that regulates the immune system and fights off disease. Also, consuming mosambi juice regularly enhances blood circulation thereby improving heart function. Further it is high in vitamin C, which boosts immunity (Bhaumik et al. 2018).

7.5.4 Respiratory Problems

Mosambi has been extensively used in balms, inhalers and vaporizers as they have anti-congestive properties. Mosambi juice can provide instant relief from asthmatic cough.

7.5.5 Skin Treatments

Mosambi is excellent in antioxidants, vitamin C and minerals and plays an important role in skincare. Its juice is used as an alternative medicinal supplement and vitamin. It possesses antioxidant, antibiotic and disinfectant properties. It is used in manufacture of many beauty products. It is used to cure skin problems like pigmentation, spots, pimples and blemishes. It is also used in treatment of cracked lips. Mosambi juice has anti-ageing properties. It purifies blood, improving skin problems. Its juice is often used for dry and rough skin thereby improving the skin tone (Bhaumik et al. 2018).

7.5.6 Treatment of Urinary Disorders

Mosambi being rich in potassium facilitates the detoxification by the kidneys and bladder and also prevents various types of urinary tract infections like inflammation of urinary bladder. Also, mosambi is good source of phytochemicals which exert antioxidant effect on the body. The antioxidant properties prevent bacteria from latching on the walls of the bladder, and being high in antioxidants, it scavenges free radicals and flushes out uric acid from the body thereby treating gout.

7.5.7 Anticancer Property

The limonoids present in sweet limes have anticancerous property. It fights various types of cancer. D-Limonene present in mosambi possesses anticancer activity which was established through clinical trials and studies using different cancer models (Hodgson 1967).

7.5.8 Gallstone Dissolution

D-Limonene has been clinically proven to dissolve cholesterol containing gallstones. In in vitro study, it has been shown that d-limonene can dissolve human gallstones within 2 h. Whereas, in animals, d-limonene infusion into the gallbladder dissolves and disintegrates gallstones and is later excreted through the common bile duct. Igimi et al. (1976) reported gallstone dissolution in patients after only three infusions of d-limonene.

7.5.9 Treatment of Dehydration and Sunstroke

Mosambi juice is a healthy drink which provides all the essential micronutrients required by the body. It is used as an alternative to carbonated drinks in quenching thirst. It is a better choice for athletes. It reduces the risk of dehydration and muscle cramps. Furthermore, sunstroke can be prevented by drinking fresh mosambi juice. The abundance of vitamins and minerals makes sweet lime juice healthier and hydrates your body.

7.6 Conclusion

Mosambi is a rich source of phytochemicals, ascorbic acid, water-soluble vitamin and folic acid. It is loaded with antioxidants that boost the immunity and increase resistance to infections, particularly from flu. Its juice aids in digestion and flushes out the body toxins. Mosambi is an extremely hydrating food and provides us with essential micronutrients like minerals and vitamins. It delivers lots of satiety due to its high water and fibre content and prevents constipation. It is great for weight loss management due to its high citric acid content, which controls the hunger pain and boosts metabolism. It contains limonenes, a family of chemicals that possess nutraceutical property. Also, mosambi is a rich source of polyphenols with good antioxidant properties, which makes its use as an ingredient in the preparation of various products to make them functional foods.

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Indian Bael

8

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Abstract

Bael, *Aegle marmelos* (Linn.) Correa, is an Indian native tree spread in many regions of the world, commonly known by the names wood apple and stone apple. *Aegle marmelos* is a subtropical, usually medium to big-sized deciduous tree growing well in dry forests of plain and hilly area up to a height of about 1200 m above sea level and can adapt to a wide range of habitat. *Aegle marmelos* is widely recognized from prehistoric times for its therapeutic characteristics. Many parts of bael tree, including stem, bark, root, leaves, fruits, and seeds, find usage in traditional medicine. Various parts of this tree are being used from prehistoric times in traditional system of medicine for wound healing; curing digestive disorders, ulcers, hypertension, and respiratory infections; relieving dysentery, diarrhea, and constipation; and in numerous other ailments. It performs several biological activities like antimicrobial, antidiabetic, anti-inflammatory, cardioprotective, diuretic, radioprotective, and others. It exhibits strong antioxidant properties due to presence of many phytochemicals like marmesinin, eugenol, and other phenolics. Studies on animal model have reported no toxicological and fatal consequence of bael extract consumed up to a maximum dose of 250 mg/kg body weight.

Keywords

Bael · Antimicrobial · Antidiabetic · Anti-inflammatory · Antioxidant activity

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8.1 Botanical Name and Common Name

Bael, *Aegle marmelos* [L.] Correa, is usually famous as wood apple and belongs to the Rutaceae family. In informal expressions, bael is also identified by different names like bilva or bael (in Hindi), golden apple (in English), Bengal quince, Indian quince, holy fruit, etc. (Sharma et al. 2007; Maity et al. 2009). The other less-known vernacular names of bael are mentioned in Table 8.1. *Aegle marmelos* is the Latin term for one of the Hesperides, the three sisters who were helped by a dragon, who protected the golden apples of the goddess Hera. The word *marmelos* has been taken from the Portuguese word "marmelos de," which means marbled (Rajasekaran et al. 2009). Bael is mentioned to be indigenous to the Indian subcontinent and principally observed in the tropical and subtropical regions. The bael tree originates from Central India and Eastern Ghats of India. The scientific classification of *Aegle marmelos* is as under (Sharma and Dubey 2013):

Kingdom: Plantae
Order: Sapindales
Family: Rutaceae
Sub family: Aurantioideae

Table 8.1 Vernacular names of bael in various languages

Language	Name/s of bael
English	Bael, Bengali quince, Indian quince, wood apple
French	Oranger du Malabar
Burmese	Ohshit, Opesheet
Indonesian	Mojo tree
Malay	Pokok Maja Batu
Nepali	Gudu
Thai	Mapin, Matum, Tum
Vietnamese	Mbau, Nau, Trai Mam
Sanskrit	Shreephal, Bilva, Bilwa
Hindi	Bel
Bengali	Bel, Bael, Shreefal
Marathi	Bel, Bael, Kaveeth
Tamil	Kuvilam, Vilvam, Sivadurumam, Vilva Maram, Vilva Pazham
Gujrati	Bil
Telugu	Bilvamu, Maredu
Assamese	Bel, Vael
Kashmiri	Bel
Oriya	Belo
Persian	Shul
Sindhi	Kathori
Urdu	Bel

Source: Rajasekaran et al. (2009)

Genus: *Aegle*
Species: *A. marmelos*

8.1.1 Introduction

The traditional system of medicine mentions about 6000 plants that possess some kind of medicinal properties; however, of these 6000 plants, merely 350 species are utilized for various purposes. *Aegle marmelos* (L.) Corr. is one of these 350 species classified under the family Rutaceae, which has many essential functions in everyday life. Bael is one of the imperative aromatic medicinal trees native to Indian region. The bael tree's most of the parts find their utility in the preparation of traditional herbal medicines. This plant is very important considering its ethnomedicinal and religious significance (Malviya et al. 2012).

8.1.2 History

A. marmelos has its origin in central to northern parts of India, though this tree is commonly located all over the Indian subcontinent as well as in many countries of the world including Bangladesh, Burma, Ceylon, China, and Thailand (Brijesh et al. 2009). It is believed that the methods of ripening fruits of this tree were described in early Buddhist and Jain literature (8000–325 BC). The famous paintings of Ajanta Caves portray the bael fruit (Kaur and Kalia 2017), which signifies the importance of this tree and its fruit. Hiuen Tsiang, the Chinese Buddhist pilgrim, noticed and mentioned the presence of this tree when he came to India in 1629 AD (Sambamurthy and Subrahmanyam 1989). Besides abundance of this tree in the Indian subcontinent, the *A. marmelos* tree has been reported to be cultivated in many other countries like Java, Northern Malaya, Philippine Island, and Ceylon where it was first cultivated in 1914 (Morton 1987). The bael fruit in Europe was first time introduced in about 1959 (Knight Jr 1980).

Being native to India and having originated in central to northern parts of India, *A. marmelos* is mostly populous and found densely located in tropical and subtropical regions. This is also due to the fact that this tree is indigenous to Indian subcontinent. This tree was not mentioned to be domesticated but is observed as a non-domesticated and wild tree in the lower parts of the Himalayas extending to the height of about 500 m. Besides the foothills of Himalayas, the bael tree is, moreover, also located and grown in hilly parts of Indian states like Jharkhand, Madhya Pradesh, Uttaranchal, and even the Deccan Plateau, as well as all along the east coast (Sharma et al. 2007) suggesting that this tree proliferates in many kind of conditions.

The bael is also popularly identified in the history of Hindu religion as Vilvam, which is again identified by the name "Shivadruma" meaning the tree of Lord Shiva, and is considered as an auspicious tree by Hindus. The leaves of *A. marmelos* are being offered in prayers to Lord Shiva since ancient time. As the three leaves of this tree form a group together, it is assumed that these three leaflets of *A. marmelos* are also symbolical of three Gunas (Satva, Rajo, Tamo), the three eyes of Lord Shiva, the Trimurthies (Brahma, Vishnu, Shiva), and many other auspicious threes described in the Hindu literature. Being related with many virtues of Hindu religion and thus being considered as sacred, *A. marmelos* tree is frequently found growing near the premises of temples and personal dwellings of Hindus. The root, flower, leaves, fruit, and bark are being used as drugs in the Siddha system of medicine (Rajasekaran et al. 2009).

A. marmelos is often mentioned as an insignia of prosperity and fertility and thus this tree is considered to be very auspicious as described in the ancient Sanskrit poems. The bael fruit has been described under the name of "marmelos de benguala" by Garcia d'orta, who had served as physician to the viceroy of Goa in the sixteenth century. He also mentioned the use of bael fruit for curing dysentery. *A. marmelos* was made official in the pharmacopoeia of India in 1869, wherein it is recommended as a remedy in atonic diarrhea and dysentery, in irregularity of the bowels, and in habitual constipation (Rajasekaran et al. 2009).

8.1.3 Production

Bael is considered as a very important tree due to its medicinal properties. However, unlike other fruit trees, the cultivation and production of bael is not extensive. This may be due to difficulty in the processing of fruit and its unappealing sensorial characteristics compared to common fruits. The production of bael in India was 0.08583 MT in 2015–2016 (Anonymous 2015) from several major producing states like Jharkhand, Odisha, Madhya Pradesh, Rajasthan, Uttar Pradesh, Chhattisgarh, and others. It takes about 10–11 months for a bael fruit to mature and ripe (Anonymous 2012).

There are many cultivars of bael fruit. There are about 12 cultivars, namely Kagzi Etawah, Lamba, Deoria Large, Basti No. 1, Sewan Large, Chakaiya, Baghel, Gonda No. 1, Gonda No. 2, and Gonda No. 3. Among these cultivars, the Mirzapuri, Deoria Large, and Sewan Large are identified as superior and better with respect to taste and quality parameters as compared to other cultivars. A number of cultivars have been selected based on yield and fruit quality, which are the best among the others (Sharma and Dubey 2013). These cultivars are as below:

NB 5 This cultivar has medium-sized fruit. The fruit is round in shape and attains smooth surface at maturity. The fruit of this cultivar contains low mucilage, moderate amount of fibers, and possess soft flesh with excellent taste.

NB 6 The fruit of this cultivar is also medium in size. The fruit shape is round and fruit develops with smooth surface. The rind of fruit is very thin and there are very few seeds in the flesh. The flesh is soft, contains low mucilage, and is mildly acidic in nature.

Pant Shivani Pant Shivani is a mid-season cultivar. The fruits of this cultivar are ovoid–oblong in shape. The average weight of the fruit is 2 kg and it becomes lemon color on ripening. The rind of the fruit is medium thick. The flesh contains medium fiber and mucilaginous matter. The flesh of this cultivar is light yellow in color with pleasant and attractive flavor and good taste.

Pant Aparna Pant Aparna is considered as late cultivar and bears small-sized fruits. The weight of fruit of this cultivar ranges from 0.6 to 0.8 kg. The fruit is globose in shape and contains very few seeds in the flesh. The flesh of the fruit is yellow in color and has low acidity and fiber content. The flesh is sweet, tasty, and possesses good flavor.

8.1.4 Botanical Description

Aegle marmelos plant grows in a subtropical region and has the ability to grow in regions located up to 1200 m above the sea level. The plant can also be cultivated and nurtured in the arid forest of mountainous and plateau regions. The bael tree has an ability to adapt to a broad array of habitation and thus can be planted all over the world (Sharma and Dubey 2013). *A. marmelos* is usually intermediate to tall heighted, leaves shedding, and branched tree with its axillaries. The leaves of this tree are trifoliate type and are about 1 inch long. The flowers are short whereas the fruits are globular in shape (Das and Roy 2012).

Aegle marmelos typically grows very slowly up to a height of about 12–15 m and have very short trunk. The bark of this tree is thick but soft and flaking. The bark keeps on spreading with the maturity of the tree. Some varieties of *A. marmelos* have spiny branches. The lower branches are drooping and grow in downward direction. The wounded branches of this tree exude a clear but gummy sap that is quite similar to gum Arabic in appearance. The long strands of this exuding sap suspend in downward direction before solidifying slowly. The sap of this tree initially tastes sweet. However, after some time of consumption, the sap irritates to the throat. The tree sheds its leaves annually and these leaves are of alternate type. The leaves may grow either singly or in twos or threes. The leaves are usually oval in shape, pointed, and have shallowly toothed leaflets. The leaves are medium in size and may grow from 4 to 10 cm long and are of 2.5 cm in width. The terminal leaves may have a long petiole. The newly grown foliage has glossy appearance and is pinkish in color. The mature leaves on bruising emit a noxious odor. However, the flowers possess fragrance and sweet-type aroma. The young branchlets contain flowers blooming in clusters. There are four curled thick petals on each flower. The petals are green and yellowish in color from outside and inside, respectively. There are about more than 50 yellowish-green colored stamens. The fruit shapes vary with the variety. The fruits of *A. marmelos* are of varying shape. Their shape varies from round to oblong.

The diameter of the fruit varies from 5 to 20 cm. The young fruit is greenish in color. The color changes to yellowish-brown on ripening. The fruit has hard rind and woody surface, which may be plane or somewhat granule-like surface bearing a globular sear at the place where it gets attached to peduncle. The rind is about 1.5–3.0 mm thick. The fruit has dotted minute oil glands. These glands possess characteristic aroma. The fruit has tough centrally located core in the inside. The core contains about 8–20 difficult to identify triangular-shaped segments containing pulp line with skinny and dark-orange walls. The pulp is more or less astringent and have characteristic sweet aroma to it. The pulp is pale orange in color, has pasty consistency, and is resinous in appearance. There are about 10–15 seeds present in the pulp. The seeds in the pulp are flat, oblong in shape. The length of the seeds is about 1 cm. The seeds bear wool-like hairs and every seed is contained in a bag of gum-like material and mucilage that solidify on getting dried (Hiremarh et al. 1996; Kaushik et al. 2008; Rajasekaran et al. 2009).

8.2 Antioxidant Properties of Fruit, Juices, Seeds, Peels, Wastes, and Its Products

Bael is reported to exhibit strong antioxidant and radical scavenging activities. The unripe bael fruit depicts higher percentage of free-radical inhibition than the ripe fruit. Sekar et al. (2011) studied the antioxidant activity of methanol and aqueous extract of fruit pulp using different assays including ABTS—2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid—radical scavenging assay, reducing power assay, H_2O_2 radical scavenging assay, superoxide radical scavenging assay, nitric oxide scavenging assay and DPPH—1,1-diphenyl-2-picrylhydrazyl—radical scavenging method. Significant antioxidant activity is exhibited by both the extracts, alcoholic as well as aqueous. The bael fruit has potent free-radical scavenging and antioxidant effects. Abdullakasim et al. (2007) found that phenolic compounds are present in abundant quantities in the fruit drink prepared from *A. marmelos* fruit and these exhibit good antioxidant activities.

The bael fruit contains phenolics, carotenoids, flavonoids, and ascorbic acid as principle antioxidant compounds (Morton 1987; Roy and Khurdiya 1995). Charoensiddhi and Anprung (2008) determined the antioxidant activities of bael fruit extracts in terms of EC_{50}. The antioxidant activities of bael fruit extract observed were 6.21 μg/μg DPPH whereas the antioxidant activities determined by FRAP—ferric-reducing ability of plasma—assay was 102.74 μM TE/g dry weight of the fruit. The amount of total phenolics and total flavonoids in bael fruit pulp found was 87.34 mg GAE—gallic acid equivalent—and 15.20 mg CE—catechin equivalent—per gram dry weight of the fruit pulp. The total carotenoid content of bael fruit pulp as reported by Charoensiddhi and Anprung (2008) was 32.98 μg/g dry weight. The ascorbic acid content of the bael fruit pulp was 26.17 mg/100 g dry weight.

The free-radical scavenging capability of *A. marmelos* fruit pulp aqueous extract has been studied by Vardhini et al. (2018) using DPPH method. The study found that at 300 μg/mL concentration, the aqueous extract of fruit pulp depicted maximum radical scavenging activity (60.70%). Moreover, the study mentioned that the aqueous extract of *A. marmelos* exhibited strong ability to scavenge the free radicals as evidenced through reduction in the stable DPPH (1,1-diphenyl-2- picrylhydrazyl) compound. The increased concentration of fruit pulp extract resulted in an increase in the radical scavenging capability. The extract had IC_{50} value of 183.58 μg/mL concentration and was well compared with standard (ascorbic acid). The extract of *A. marmelos* fruit pulp had maximum $ABTS^{\bullet +}$ scavenging activity of 95.77 ± 6.70% at 30 μg/mL concentration depicting that the extract could demonstrate high antioxidant activity. The phosphomolybdenum reduction method was also employed to measure the total antioxidant activity of aqueous extract of *A. marmelos* and found that the maximum phosphomolybdenum reduction was 87.81 ± 6.14% at 120 μg/mL concentration whereas the maximum Fe^{3+} reduction was 52.05 ± 3.46% at 120 μg/mL concentration.

It was found that the fruit pulp extract obtained from *Aegle marmelos* shows powerful radical scavenging activity. The observed EC_{50} concentration of superoxide, nitric oxide, DPPH, and the hydroxyl radical scavenging activities are 39.44, 84.14, 30.52, and 22.37 μg/mL, respectively, which are well comparable with gallic acid and ascorbic acid as standard antioxidants (Prathapan et al. 2012).

The extract of *A. marmelos* fruit pulp in water and alcohol system demonstrated at par DPPH scavenging capability at 100 μg/mL. The aqueous extract had the scavenging power of 44.36 ± 2.09% while the alcoholic extract had 40.12 ± 5.36% scavenging ability. Further, the IC_{50} value of aqueous extract of *A. marmelos* fruit pulp was 92.648 ± 30.68 μg/mL and the IC_{50} for alcoholic extract was 106.15 ± 25.33 μg/mL, while the standard ascorbic acid depicted 63.99 ± 25.24 μg/mL as IC_{50} value. The observed ferric-reducing power of water and alcohol extracts of *A. marmelos* fruit pulp at a concentration of 100 μg/mL was 50.33 ± 2.08% and 28.7 ± 12.05%, respectively. Furthermore, at a concentration of 100 μg/mL, the radical scavenging activities of both the aqueous and ethanol extracts of *A. marmelos* fruit pulp against the free radicals induced and released by nitric oxide (NO) were noticeable. The inhibition percentage of aqueous extract for nitric oxide induced radicals was 63.74 ± 5.54 while that of alcoholic extract produced 52.02 ± 5.37% inhibition of radicals released from nitric oxide. The superoxide radical scavenging capability of aqueous and ethanol extracts was strong. The ethanol extract (147.89 ± 44.86%) showed more capability to scavenge the superoxide radicals than the aqueous extract (91.41 ± 17.36%) at the same concentration of 100 μg/mL. *A. marmelos* fruit pulp exhibited effective ABTS radical scavenging activity. The aqueous extract of *A. marmelos* depicted 94.36 ± 1.42% of radical scavenging activity. Similar results of ethanol extract (95.12 ± 4.37%) were recorded for inhibition of ABTS radicals at 100 μg/mL concentration. The aqueous and alcohol extracts also efficiently scavenged the hydrogen peroxide radicals in a concentration dose-dependent way. The aqueous extract was able to scavenge more radicals (77 ± 3.67%) than the alcohol extract (69.0 ± 16.40%) at a concentration of 100 μg/mL. The aqueous as well as alcohol extracts showed high and quite similar IC_{50} values, the aqueous extract showing slightly more IC_{50} value (56.53 ± 12.44) than the alcohol extract (52.19 ± 18.37). These values were far greater than the IC_{50} value of standard (26.67 ± 7.51) (Rajan et al. 2011).

Sathya et al. (2013) observed that the ethanol extract of *A. marmelos* shows dose-dependent increase in the antioxidant activity (46.08% for 5 mg/mL, 50.56% for 10 mg/mL, and 54.32% for 15 mg/mL). The study of Sathya et al. (2013) indicated that the antioxidant activity of this extract is principally attributed to the presence of total phenolic compounds in the extract. Among the three different solvents used, maximum phenol compound content was seen in ethanol extract (1.92 mg/g) while water extract (1.51 mg/g) showed least content of phenolic compounds.

The extract of *A. marmelos* leaf in methanol was studied by Siddique and Mujeeb (2010) for its in-vitro antioxidant activity. The antioxidant activity was assessed through different standard methods including ferric-reducing power, DPPH method, and hydrogen peroxide scavenging activity. The in-vitro study indicated that the methanol extract of leaves of *A. marmelos* possesses strong antioxidant activity. The estimated IC_{50} value of this extract was 23 ± 0.08. This extract, therefore, could be utilized for inhibiting the free radicals. The leaves of *A. marmelos* have been studied by Reddy et al. (2012) for their polyphenol content, antioxidant activity, and presence of other phytochemicals using a series of solvents. This study displayed that the antioxidant activity of water extract of *A. marmelos* is more (92%) than the standard antioxidant BHT—butylated hydroxytoluene (81%). The extract, owing to the presence of various phytochemicals like glutathione (GSH), ascorbic acid, and tocopherol, showed powerful scavenging activity against radicals.

8.3 Characterization of the Chemical Compounds Responsible for Antioxidant Properties and the Pathways Involved in the Biological Activities

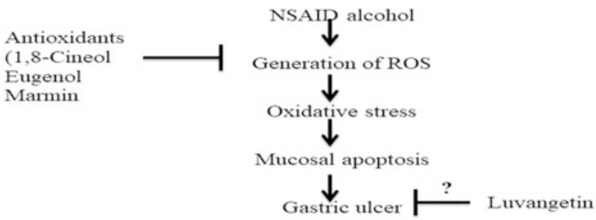
8.3.1 Pathways Involved in Biological Activities

The bael extract exhibits several medicinal properties and biological activities like anti-ulcer property, antidiabetic property, antimicrobial property, antioxidant property, glycemic-reducing property, and others. These medicinal properties and the biological activities of *A. marmelos* are discussed in a later section of this chapter under the subhead "Health Benefits." These biological activities of *A. marmelos* are attributed to the presence of various bioactive compounds.

The anti-ulcer property of *A. marmelos* fruit extract is considered to be due to luvangetin present in the fruit. The oxidative kind of stress development basically mediates the gastric ulcer, and the particular compounds responsible for avoiding the ulcer advancement may act by inhibiting the onset of oxidative stress in the gastro-duodenal mucosa. It is also proposed that the presence of hydroxyl associated with the aromatic ring in phenolic compounds makes them a potent antioxidant and possible causative agent for its anti-ulcer activity (Maity et al. 2009). The pathway indicating the possible mode of action of these anti-ulcer compounds is depicted in Fig. 8.1.

Bael fruit's aqueous extract, administered orally as well as intraperitoneally, demonstrated glycemic-lowering response in the diabetic rats induced with

Fig. 8.1 Possible mode of anti-ulcer action of bael extracts (? = not confirmed; − = inhibition) (Source: Maity et al. 2009)



streptozotocin (Kamalakkanan et al. 2003; Kamalakkannan and Prince 2005). It is observed that the fruit extract of *A. marmelos* contains coumarin compounds, which show antidiabetic property. The release of insulin from the beta cells of Islets of Langerhans is potentiated by the presence of coumarin compounds (Kamalakkannan and Prince 2003). The mechanism accountable for the antidiabetic property of *A. marmelos* is multidirectional because the level of blood sugar and glycosylated hemoglobin is lowered by the application of fruit extract in diabetic rats. Moreover, the glycogen in liver and the plasma insulin is also seen elevated in diabetic rats as a result of usage of *A. marmelos* (Kamalakkanan et al. 2003). The application of aqueous extract prepared from the seeds of bael reduces the concentration of glucose sugar in the blood of both the normal and acute diabetic rats (Kesari et al. 2006). Thus, it indicates that the mechanism of antidiabetic action of bael extract may have been attributed either to stimulation of sugar utilization or increased release of insulin or both, as has been mentioned by Sachdewa et al. (2001). Many studies have also mentioned that *A. marmelos* significantly reduces the serum sugar level and improves the capability of usage of the external sugar as well as augments the plasma insulin levels in artificially induced diabetic animal models (Ponnachan et al. 1983; Rao et al. 1995; Sharma et al. 1996; Sachdewa et al. 2001; Gholap and Kar 2004; Sabu and Kuttan 2004). The application of leaf extract of *A. marmelos* on diabetes-affected pancreas demonstrates enhanced operational state of beta cells and also assists in the regeneration of components of streptozotocin-destructed pancreas (Upadhyay et al. 2004). The possible mechanism of antidiabetic property of bael extract is illustrated through a composite diagram in Fig. 8.2.

Antihyperlipidemic activity of bael extract is well known and is documented by several studies (Kamalakkannan and Prince 2005; Kesari et al. 2006; Vijaya et al. 2009). Some studies (Kamalakkannan and Prince 2005; Kesari et al. 2006) have indicated that the extract of bael fruits and seeds at a concentration of 250 mg/kg when given to rats induced with streptozotocin resulted in noticeable decrease in the lipid profile of serum and tissues. Vijaya et al. (2009) also reported decrease in the serum cholesterol and triglycerides in high-lipid rats treated with Triton WR 1339 on application of bael leaves' extract prepared in ethanol. This decrease in serum lipids may be attributed to the reduced movement of fat from the surrounding depots and serum lipid formation. The treatment with *A. marmelos* extract initiates the hydrolysis of triglycerides and reduces circulatory level of blood cholesterol by declining fat mobilization from peripheral adipose tissues as illustrated in Fig. 8.2. The extract is also believed to be potentiating and triggering the use of glucose. The high amount of fatty acids and the metabolic products of fatty acids may frequently hamper the

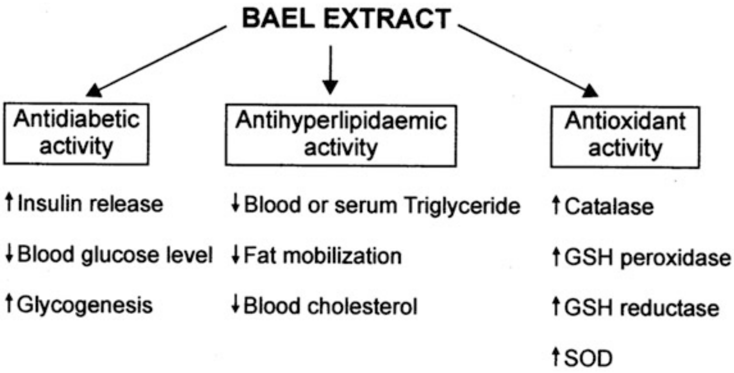


Fig. 8.2 Diagrammatic illustration of the possible antidiabetic, antihyperlipidemic, and antioxidant activities of bael (↑ = increase; ↓ = decrease). (Source: Maity et al. 2009)

activity of Na^+/K^+-ATPase (Kamalakkannan and Prince 2005). Therefore, the reinstatement of usual working of Na^+/K^+-ATPase path may be favored by the lesser concentration of circulatory fatty acid. This may be the necessary pathway for appropriate reduction of glucose sugar in animals affected by diabetes.

Significant antitumor effect has been observed on administration of the bael extract at a concentration of 400 mg/kg. The exact mechanism behind this antitumor property is not comprehensively known. However, Jagetia et al. (2005) opined that the tumor cells may die and apoptosis induction may occur due to the availability of skimmianine in the leaf extract of *A. marmelos*. Furthermore, Costa-Lotufo et al. (2005) during their study on brine shrimp found that the extract of *A. marmelos* plant exhibited cytotoxicity against tumor cell lines. The extract of *A. marmelos* is also believed to possess proliferation-reducing property against breast cancer cell lines (Lambertini et al. 2004).

The leaves, roots, and fruits of *A. marmelos* and their extracts have been found effective in reducing and inhibiting the growth of many bacterial strains. George et al. (1947) and Joshi and Magar (1952) proved the effectivity of the extract of *A. marmelos* leaf on *Escherichia coli*. The essential oil obtained from the leaves of bael tree is also found to be effective and demonstrated the antifungal property against many animal and human fungi. The root extract of this tree prepared in ethanol has depicted its action against *Aspergillus fumigatus* and *Trichophyton mentagrophytes* (Pitre and Srivastava 1987). The extract of bael fruit in methanol as well as water is found to be powerful in reducing and inhibiting the growth of *Salmonella typhi*, which has resistance to many drugs. The extract of bael fruit in methanol was found more effective and potent than the bael fruit extract in water. The bael fruit extract in methanol has the minimum inhibitory concentration (MIC) value of 256 µg/mL (Maity et al. 2009).

The extract of *A. marmelos* is reported to inhibit spore germination. The possible inhibition of spore germination may be due to the interference of calcium ion–dipicolinic acid metabolic pathway by the essential oil present in the bael leaves. The

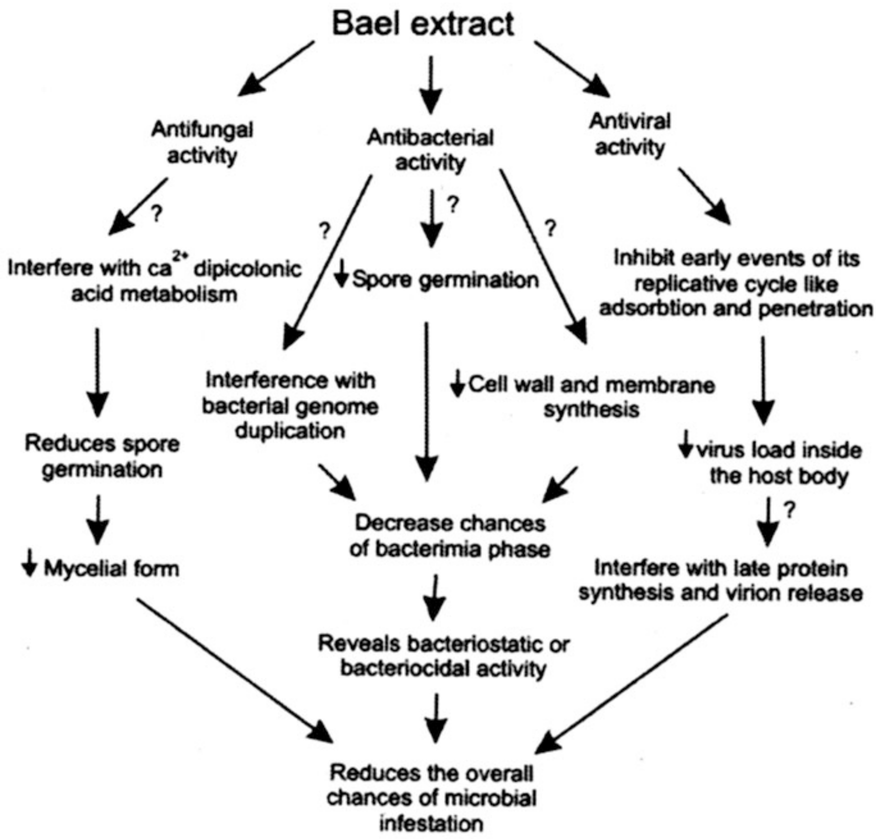


Fig. 8.3 Diagrammatic representation of the antifungal, antibacterial, and antiviral activities of bael extracts (↑ = increase; ↓ = decrease; ? = not confirmed). (Source: Maity et al. 2009)

germination of bacterial and fungal spores is influenced by the availability of either cationic calcium ions–dipicolinate and/or free calcium ions or both of these in the medium and within the microorganism. The spore germination or its dormancy is dependent on many factors; one of the major factors is the absorption of calcium ions and its usage (Pelzar et al. 1998). Therefore, the extract is found to exhibit activity against fungi by reducing the fruiting fungal body within the host or in the solid medium. This may be the likely mechanism of the antifungal property of *A. marmelos* (Rana et al. 1997). Nevertheless, its exact protective property is hitherto to be comprehensively investigated. A general pathway for antifungal property of *A. marmelos* extracts is illustrated through Fig. 8.3. The mechanism of antibacterial action of *A. marmelos* may be attributed either to the obstruction of protein formation at transcription or translation, or peptidoglycan formation at membrane level, or both of these. Cuminaldehyde and eugenol show activity against various strains of bacteria and as these compounds occur in the leaf extract of the bael tree, the antibacterial property of the extracts obtained from the leaves of *A. marmelos* may be due to the presence of these compounds in the leaves (Katayama and Nagai 1960; Duke 1992). Figure 8.3 illustrates the probable approach of antibacterial property of *A. marmelos* extract.

The bael tree extracts have depicted strong action over many viruses. *A. marmelos* has demonstrated the antiviral property in the beginning stages where replication of virus is slow. Moreover, the *A. marmelos* extract also has minimum host cytotoxicity as opposed to current chemotherapeutic agents like ribavirin, which acts against viruses. Further, these chemotherapeutic agents, however, initiate their action in very later stages of replication of virus and they also show adverse effects on the host (Fenner et al. 1993). Marmelide, which have shown property against virus infection hindering the replication cycle of virus in the early stages, is the most effective virucidal agent (Badam et al. 2002). However, there is need to undertake studies examining effects of bael extract and determining it as an antiviral agent in order to assess its degree of potentiality. Dhar et al. (1968) revealed the noticeable antiviral property of extract of bael fruit in ethanol against the Ranikhet disease virus. Babbar et al. (1982) found that though the extract of bael fruit demonstrates interferon-like property against the Ranikhet disease virus, however, this extract is ineffective against the vaccinia virus. Thus, though bael is supposed to have the viricidal activity, its potentiality needs to be studied and validated before its utilization as an effective antiviral agent in the near future.

A. marmelos have radioprotective effects against gamma radiation. Plant extract is utilized for restoring the radiation-induced therapeutic injuries (Bhatti et al. 2013; Jagetia et al. 2006). It has been found that the bael extract diminishes harmful effects induced by radiation and it is also toxic free. The extract of *A. marmelos* is reported to scavenge the radiation-induced harmful free radicals and thus thereby may possess radioprotective property. This may be the mechanism behind its function as a radioprotective agent (Jagetia et al. 2003). The radioprotective action of bael plant is also believed to be due to its capability to absorb the free radicals as well as to arrest the peroxidation of lipid. The extract of bael plant increases the amount of glutathione in many parts like kidney, stomach, intestine, and liver, which may be responsible for making bael plant extract a radioprotective agent (Jagetia et al. 2004a, 2006) because radiation is said to reduce the level of glutathione, depending on the magnitude of radiation dose (Korkina and Afanas'ev 1997). The study by Korkina and Afanas'ev (1997) found that along with decreased glutathione levels, the radiation also results in increasing the peroxidation of lipids, based on the dose of radiation received. Bael leaf extract significantly prevents decrease in glutathione concentration as well as lipid peroxidation. Animals exposed to radiation show signs of sickness and mortality, which further leads to peroxidation of lipid in the kidney, liver, intestine, and stomach as well as reduction in the GSH level. Animals treated with the extract of bael fruit before exposing them to radiation displayed noticeable reduction in the peroxidation of lipid elevation in the concentration of GSH (Jagetia et al. 2004b).

8.3.2 Compounds Responsible for Antioxidant Properties

The different biological activities, like antioxidant activity, antimicrobial activity, antidiabetic activity, antihyperlipidemic activity, and other ethnomedicinal properties of *A. marmelos* are attributed to the presence of many phytochemicals in it. Chemical assessment has revealed that the total phenolic compounds and flavonoid contents in the aqueous extract of fruit pulp of *A. marmelos* exhibit antioxidant activities. The total phenolic content found in fruit pulp extract of *A. marmelos* was 343.00 ± 1.33 μg/mg of GAE and the flavonoids of the extract was 21.92 ± 1.38 μg/mg of QE or quercetin equivalent (Vardhini et al. 2018). Prathapan et al. (2012) found that the *A. marmelos* fruit pulp extract exhibited strong scavenging activity against hydroxyl radicals and is comparable with the scavenging activity of catechin. The phenolic compounds are considered as donors of electron by virtue of which they are likely to accelerate the conversion of hydrogen peroxide to water molecule. Further, the hydroxyl substitutions of phenolic compounds have hydrogen transferring capacity. This phenomenon may be responsible for the hydroxyl radical scavenging activities of *A. marmelos* fruit pulp.

According to Rajan et al. (2011), the bioactive compounds present in *A. marmelos*, like phenolic compounds and flavonoids, are responsible for the antioxidative characteristics of *A. marmelos* fruit pulp. Polyphenols are identified to demonstrate medicinal activity. They also exhibit strong physiological activity. Rajan et al. (2011) opined that the compounds like flavonoids containing hydroxyl groups show strong radical scavenging activity. Many studies (Vidhya and Devaraj 1999; Ogata et al. 2000; Jagetia et al. 2003; Vimal and Devaki 2004) have indicated that the active compounds in *A. marmelos* like eugenol and marmesinin may also contribute to antioxidant and radical scavenging activities since such compounds have separately revealed their activity against oxidative stress. Eugenol ($C_{10}H_{12}O_2$), present in *A. marmelos* leaf extract, has potent antioxidant properties (Nigam and Nambiar 2015).

Reddy et al. (2012) reported the presence of tocopherol, glutathione, and ascorbic acid in considerable amounts, which is responsible for the significant scavenging activity of water extract of *A. marmelos*. According to Sathya et al. (2013), the antioxidant activity of bael is majorly attributed to the presence of phenolic compounds. In normal and streptozotocin (STZ)-induced diabetic rats, *A. marmelos* exhibited strong free-radical scavenging activity, which may be due to the content of Umbelliferon-α-D-glucopyranosyl-(2I → 1II)-α-D-glucopyranoside (UFD) compound in *A. marmelos* (Sabde et al. 2011; Sankeshi et al. 2013). Many studies have indicated that the leaf extracts of *A. marmelos* possess powerful free-radical scavenging activity, which may be due to the antioxidative phytochemicals such as flavonoids, alkaloids, sterols, tannins, phlobatannins, and flavonoid glycosides present in the leaf extract (Maridonneau-Prini et al. 1986; Rastogi and Mehrotra 1991; Uddin and Ahmad 1995; Korkina and Afanas'ev 1997; Kar et al. 2002; Jagetia et al. 2003; Rajadurai and Prince 2005).

8.4 Health Benefits

Bael (*A. marmelos*) has many health benefits and is widely used in different health systems since ages. The usage of *A. marmelos* is emphatically mentioned in the traditional Indian system of medicine. About every part of *A. marmelos* finds its use for medicinal purpose. Many medicinal properties of bael are well documented, which include its activity against microorganisms, glycemic-lowering property, diarrhea-curing property, inflammation-resistant property, wound-healing property, gastro-protective property, radioprotective property, its effect as demulcent, as insecticidal, as analgesic, and others. Many demographic and social studies have highly recommended this plant with almost all its parts, including roots, bark, leaves, and fruits, all finding tremendous ethnomedicinal usage. Though it is difficult to digest the fruits of *A. marmelos* directly, it is extensively used as laxative. It is reported that the problems related to digestion and diarrhea can be cured by consumption of the water extract of unripe bael fruit. Numerous ailments including ulcer, hypertension, diabetes, and many others can be prevented and cured by the consumption of extract of the bael fruit and leaves. This extract also has wound-healing potential. The leaves of *A. marmelos* have several medicinal functions, like in sinusitis and dyspepsia, and its use is well documented. The usage of bael leaves increases the ocular health and aids in preventing the different sexual problems. Bael leaves are also reportedly used in the treatment of abdominal pain, tremble of the heart, in the removal of urinary troubles, and in the treatment of anorexia, melancholia, and dyspepsia. The water-boiled extract of roots, bark, and leaves are used as expectorant and in the treatment of diseases related to hearing, eye sights, and breathing (Upadhyay 2015).

Powerful antimicrobial property against many pathogenic microorganisms is exhibited by the essential oil isolated from the leaves of bael tree (Brijesh et al. 2009). Traditional system of medicine prescribed the usage of bael to provide relief to the patients suffering from constipation and additional gastrointestinal troubles. It is also recommended for smooth bowel movement. Bael phytochemicals possess antineoplastic, radioprotective, chemoprotective, and chemopreventive properties, and exhibit anticancer (Baliga et al. 2012) antidiabetic, antihyperlipidemic, antioxidant, and antidiabetic activities (Kumar et al. 2013). The various health benefits and medicinal properties of *A. marmelos* are briefly described in the following section.

8.4.1 Anti-asthmatic Effect

Asthmatic and allergic manifestations essentially require activation of histamine receptors. The alcoholic extract obtained from the leaves of *A. marmelos* antagonizes the contraction induced by histamines and demonstrates its helpful relaxant effect on ileum and tracheal chain isolated from guinea pig. This suggests that the extract of *A. marmelos* arrests the activity of H1-receptor, which possibly further underlines its anti-asthmatic effect (Arul et al. 2004).

8.4.2 Anticancer Activity

Cancer is reported to be the second most fatal disease resulting in the deaths in not only developing but also developed countries, and thereby being a major public health concern (Agrawal et al. 2012a, b). *A. marmelos* is documented to be utilized in the folk medicine of Bangladesh for the treatment of cancer (Costa-Lotufo et al. 2005). Many studies (Lambertini et al. 2004; Jagetia et al. 2005; Lambole et al. 2010) have revealed that *A. marmelos* has noticeable antiproliferative property. The cytotoxic effect of the ethanol extract of bael fruit on SKBR3 cells in-vitro is well documented (Moongkarndi et al. 2004). The experimental studies have demonstrated that several phytochemicals present in the bael plant like citral, lupeol, cineole, limonene, and eugenol have antineoplastic properties. Studies have also indicated that various bioactive compounds like limonene, citral, rutin, and anthocyanins present in *A. marmelos* have chemopreventive properties. The presence of these compounds in the extract may have contributed to the observed effects (Baliga et al. 2012). It is documented that the proliferation of human leukemia cell lines is inhibited by imperatorin, a linear furanocoumarin isolated from the fruit of *A. marmelos* (Pae et al. 2002).

It is also postulated that the bark extract of *A. marmelos* has an inhibitory effect on the proliferation of various human tumor cell lines including leukemia, lymphoma, colon, and breast cancer cell lines in-vitro. Bioactive chemicals like butyl-*p*-tolyl sulfide, 6-methyl-4-chromanon, and butylated hydroxyl anisole have been identified in the extracts responsible for this inhibitory effect (Lampronti et al. 2006).

8.4.3 Antidiabetic Activity

The traditional medicinal system describes the use of *A. marmelos* for the control of diabetes. The organic extract and juice of bael plant are assessed for its antidiabetic properties in various in-vivo scientific experiments carried out on animal models. Antidiabetic properties of the leaves and callus of bael plant have been reported after conducting the studies on diabetic rats induced with streptozotocin. It was observed that all the extracts were capable of reducing the glucose sugar concentration in the blood of streptozotocin-induced diabetic animals. The highest antidiabetic potential is revealed in the leaves and callus extract of *A. marmelos* prepared in methanol among the various other extracts evaluated (Arumugam et al. 2008).

8.4.4 Antidiarrheal Activity

The dried fruit pulp of *A. marmelos* was documented to possess an in-vitro antidiarrheal property (Joshi et al. 2009). Gutiérrez et al. (2007) observed that the intestinal propulsion in the rats could be reduced by the application of extract of bael fruit prepared in methanol. It is reported that the bacterial colonization gets affected by the pulp of unripe bael fruit. The unripe bael fruit pulp can also affect the formation and activity of some enterotoxins. These effects suggest the different likely mechanisms of action of bael plant in preventing the infectious types of diarrhea. The mention of uses of bael plant in the ancient Indian texts as well as its persistent use by the regional communities for prevention and curing the diarrheal disorders is justified (Brijesh et al. 2009; Dhuley 2003).

The study of antidiarrheal activity of bael plant was carried out on the microorganisms responsible for diarrhea with the help of MIC method. The study revealed that the diarrhea-causing microorganisms like *Shigella flexneri*, *Shigella sonnei*, and *Shigella boydii* were powerfully inhibited by the application of ethanolic extract of bael plant. Further, this extract can also moderately inhibit the activity of *Shigella dysenteriae* (Joshi et al. 2009). Brijesh et al. (2009) also evaluated the effect of crude aqueous extract obtained from the unripe fruits of bael plant on the diarrhea-causing agents. The study revealed various properties of the extract, including its action against giardia, rotavirus, and bacterial infection. The extract demonstrated good inhibitory effect against the actions of giardia and rotavirus.

8.4.5 Antifertility Activity

The use of *A. marmelos* was observed in ethnomedicine for its antifertility effect (Jain et al. 2004). The antifertility activity of various parts of *A. marmelos* including the stem, fruit, seeds, and leaves in male animals have been revealed (Agrawal et al. 2012a, b). The dose-dependent decrease in the density of the sperms, sperm-motility, their viability, and acrosomal integrity was observed after treatment of male rats with methanol extract of bael plant. This is principally due to reduction in the serum testosterone concentration and the weight of the reproductive organs in male animals (Agrawal et al. 2012a, b). The in-vitro study indicated that the alkaloids, phenolics, and triterpenoids found in the aqueous extract of the bael plant leaves are accountable for decreasing the vitality of human sperms (Mohanraj et al. 2009). A dose of 300 mg/kg of 50% ethanol extract of bael plant is documented to result in the complete inhibition of fertility in rats (Chauhan et al. 2007; Chauhan and Agarwal 2008). These observations suggest that the extract of *A. marmelos* can be used as a male contraceptive.

8.4.6 Anti-genotoxic Activity

The extract of bael fruit was evaluated by Kaur et al. (2009) through *E. coli* PQ37 and using peripheral lymphocytes of human blood for its anti-genotoxic property. The study revealed that the extracts of bael fruit obtained using methanol and acetone solvents are extremely effective and produce the desired effect by lessening the SOS response stimulated through hydrogen peroxide. The genotoxicity of hydrogen peroxide was inhibited by more than 70% while the genotoxicity of aflatoxin B1 was reduced by over 84% with the application of methanol extract of *A. marmelos*. The gel electrophoresis assay performed using single cell displayed noticeable reduction in hydrogen peroxide induced tail moment by the application of bael plant extract. This anti-genotoxic property of bael plant extract may be attributed to the presence of different polyphenolic compounds. These polyphenolic compounds have the ability to prevent the attack of reactive oxygen species and mutagens on DNA. Furthermore, it is observed that the actions of enzymes participating in the aflatoxin B1 metabolism may be reduced by the application of this polyphenolic-rich extract (Ammar et al. 2007). It is possible that the enzymes taking part in stimulation of activity of aflatoxin B1 may get inhibited. This phenomenon may be responsible for the noticeable suppressing effect of bael plant extract against aflatoxin B1 (Kaur et al. 2009).

8.4.7 Antihyperglycemic Activity

The extract of green leaves of the bael plant has hypoglycemic property in diabetic animals (Chakarbarty et al. 1960; Rao et al. 1995). It is observed that the 75% methanolic extract of bael plant administered at a concentration of about 100 mg/kg reduces the blood sugar levels in diabetic rats induced with alloxan (Sabu and Kuttan 2004).

The extract of plant *A. marmelos* elevates the levels of reduced glutathione in the erythrocytes and reduces the malondialdehyde concentration in diabetic rats that are induced with alloxan (Upadhyay et al. 2004). Rats administered with the aqueous decoctions of the *A. marmelos* plant have showed noticeable enhancement in the tolerance of glucose sugar (Karunanayake et al. 1984). The water and alcohol extracts of *A. marmelos* at 500 mg/kg concentration resulted in hypoglycemia in usual fasted rabbits (Hema and Lalithakumari 1999). This glycemic-lowering effect of the extract of bael plant obtained in alcohol on diabetic rats induced by means of alloxan has been also reported by Bhavani and Rajeshkumar (2014). It has been noticed that the continuous uptake of bael plant extract significantly reduces the blood glucose level.

Treatment with *A. marmelos* extract is believed to annul the muscarinic M1 receptor gene expression. This gene expression gets decreased in diabetic rats, which consequently increases the vagal nerve stimulation and insulin secretion. It thereby results in having a regulatory effect on glucose homeostasis in diabetes (Gireesh et al. 2008). The extract of bael plant is also revealed to have stimulatory action on PPAR-γ in-vitro (Anandharajan et al. 2006) and in-vivo (Sharma et al. 2011).

8.4.8 Anti-Inflammatory Activity

Significant severe and mild anti-inflammatory properties of various organic extracts of *A. marmelos* leaves have been observed. *A. marmelos* extract revealed considerable anti-inflammatory property in the animal models with severe and chronic inflammation, which signify that the bael plant extract can potentially be used as an effective anti-inflammatory means. The leaves of *A. marmelos* contain the phytochemicals lupeol and skimmianine that have displayed potentiality of anti-inflammatory activity in their pure form. This may be the principle behind anti-inflammatory action of bael plant extract. *A. marmelos* leaves' extract obtained in alcohol demonstrates the optimistic relaxant effect in the ileum and tracheal chain isolated from guinea pig by antagonizing the histamine-induced contractions that indicate inhibition of H1 receptor activity (Dhankhar et al. 2011). The anti-inflammatory property of bael plant was also observed by George et al. (2016) and the authors screened phytochemical constituents of ethanolic extract of the leaves of bael plant for this medicinal property in Wistar albino rats.

8.4.9 Antimicrobial and Antiviral Activities

A. marmelos plant has been in use since prehistoric times for its antibacterial property in ethnomedicine (Baliga et al. 2011). The various extracts (aqueous, alcoholic, etc.) obtained from bael plant's different parts like roots, fruits, and leaves demonstrated positive effect in inhibiting the growth of numerous strains of bacteria. There are several reports (Rojas et al. 2003; Duraipandiyan et al. 2006; Parekh and Chanda 2007) in the literature revealing the antimicrobial properties of crude extracts prepared from *A. marmelos* plants.

The in-vivo as well as in-vitro study of the alcohol extracts prepared from the leaves and seeds of *A. marmelos* displayed significant antimalarial property over the *Plasmodium berghei* strain. The extract prepared from the seeds has revealed schizontocidal property in both in-vivo and in-vitro systems, while the extract obtained from the leaves of *A. marmelos* has displayed this property in only one of the system, in-vitro (Dhankhar et al. 2011). The extract of *A. marmelos* has been reported to have antibacterial activity on the Gram-positive bacteria owing to the presence of shahidine, a highly labile oxazoline found in the extract (Faizi et al. 2009). The hot aqueous decoction prepared from the unripe fruits of *A. marmelos* has been demonstrated to have cidal activity against giardia and rotavirus; however, the decoction showed limited activity against *E. coli* (Brijesh et al. 2009). The antibacterial activity of bael plant has been documented owing to the availability of alkaloids and coumarins isolated from the acetone extract of green fruits of this plant (Chakthong et al. 2012).

It is also postulated that *A. marmelos* possesses a broad spectrum of antibacterial properties indicating that it is effective on both Gram-positive and Gram-negative bacteria; however, specific bacterial strains like *Bacillus subtilis* are found to be resistant to the action of this plant's extract (Saradha Jyothi and Subba Rao 2010).

8.4.10 Antiviral Activity

The extracts of bark, fruit, and root of *A. marmelos* exhibit activities against human coxsackie viruses. The phytoconstituent marmelide isolated from these extracts is

Table 8.2 The IC_{50} values of various parts of bael plant against the coxsackie viruses B1–B6

Part of bael plant/compound	IC_{50} value (μg/mL)
Leaves	1000
Stem and stem bark	1000
Fruit	500–1000
Root and root bark	250–500
Pure Marmelide[a]	62.5
Ribavirin[b]	2000

Source: Badam et al. (2002)
[a]Bioactive compound present in *A. marmelos*
[b]Standard used in the assay

found to be responsible for the antiviral activity. The different parts of the bael tree like roots, bark, leaves, and fruit have been documented to have in-vitro antiviral activities and are assessed for their efficiency against human coxsackie viruses B1–B6 (Badam et al. 2002). The reported IC_{50} values of various parts of bael plant are given in Table 8.2. It is also documented that the ethanol extract of *A. marmelos* has inhibitory action against the Ranikhet disease virus (Dhar et al. 1968).

8.4.11 Cardioprotective Activity

The extract of unripe fruit of *A. marmelos* has been revealed to be used in cardiac ailments (Dhankhar et al. 2011). The fresh juice of the fruits of bael plant has been suggested to be better tolerated, less toxic, and cardiotonic in hearts isolated from the frog (Dama et al. 2010). A meta-analytic study indicated the Padma-28, a polyherbal Tibetan preparation containing extract of *A. marmelos*, to have favorable effects on patients suffering from peripheral arterial disease (Melzer and Saller 2010). A polyherbal preparation containing extracts of *A. marmelos* and five other plants has been also documented to significantly reduce the elevation in serum lipids, cholesterol, and triglycerides in an experimental model of hyperlipidemia in rats (Ansarullah et al. 2012). The water and alcoholic leaves' extracts of *A. marmelos* decreased the pulse rate and increased the amplitude and tone of contractions in isolated frog heart (Haravey 1968). The ethanol extract of leaves of bael plant is reported to be useful in suppressing the increase in serum cholesterol and triglycerides. This extract is also reported to elevate the level of high-density lipoproteins in triton and diet-induced hyperlipidemic rats (Vijaya et al. 2009).

The protective effect of the extract prepared from the leaves of *A. marmelos* on doxorubicin-induced cardiotoxicity and peroxidation of lipids in rats is reported, which is attributed to the presence of periplogenin, a cardenolide found in the extract (Panda and Kar 2006). The anti-dyslipidemic properties of leaves of *A. marmelos* were found in streptozotocin-induced diabetic rats and are believed to be due to the occurrence of lupeol in the extract (Papi Reddy et al. 2009). Aegeline, an alkaloidal-amide, found in the leaves of bael plant is also considered causative for the anti-dyslipidemic effect of *A. marmelos* observed in streptozotocin-induced diabetic rats

(Narender et al. 2007). The extract obtained from *A. marmelos* has been proposed to possess the therapeutic ability in cardiovascular disorders. This potential is attributed to the inhibition of apoptosis induced by ischemia-reperfusion stimulated myocardial injury (Ahmad et al. 2010). A high dose (500 mg/kg) of *A. marmelos* leaves' extract results in a good cardioprotective activity in rats with myocardial necrosis induced with isoproterenol; however, a low dose (100 mg/kg) is unsuccessful in showing significant cardio-protection (Khanna et al. 2010).

8.4.12 Diuretic Activity

The diuretic activity of different organic extracts of *A. marmelos* fruit in experimental models was studied by Singh et al. (2013). The experimental rats were administered with the extracts at doses of 300, 400, and 500 mg/kg. The diuretic effect was evaluated by measuring the urine volume and sodium content in the urine. The results of their study indicated that the ethanolic extract when administered at higher doses (500 mg/kg) produces significant increase in excretion of sodium (Singh et al. 2013).

8.4.13 Radioprotective Activity

The radioprotective activity of bael plant extract has been studied by Jagetia and Venkatesh (2005). In this study, the researchers treated the mice with varying doses of gamma irradiation followed by application of bael plant extract. This study revealed that mice displayed increased radiation tolerance on oral administration of bael plant extract. Further, Jagetia et al. (2006) documented the radioprotective action of *A. marmelos* extract by experimenting on the peripheral blood and small intestine of Swiss albino mice. In this study, after application of *A. marmelos* extract, the animals were given irradiation dose by exposing them to the gamma radiations. The effect of *A. marmelos* extract was studied with respect to changes in the spleen colony forming units, intestinal mucosa, and peripheral blood, as affected by radiation dose. The study revealed positive effects of application of *A. marmelos* extract against radiation-induced changes. The findings of the study of Sharma et al. (2011) also revealed that the *A. marmelos* extract noticeably decreases the harmful actions of radiations in the bone marrow and the intestine of mouse. The radioprotective effect of extract of *A. marmelos* fruit in hydroalcohol has also been studied and reported by Jagetia et al. (2004b) in mice exposed to varying doses of gamma radiation. This study observed that the *A. marmelos* extract afforded maximum protection against the effects of gamma radiations when the mice were given the extract dose of 20 mg/kg for five successive days prior to irradiation.

8.4.14 Ulcer-Healing Potential

It has been observed that the *A. marmelos* fruit pulp extract significantly reduces the activity of catalase enzyme, superoxide dismutase, mucosal thickness, and the concentration of glutathione in the albino rats. The albino rats treated with the fruit pulp extract of bael plant demonstrated noticeable rise in alanine aminotransferase, lipid peroxidation activity, aspartate aminotransferase, and ulcer index. These results indicate that *A. marmelos* has the anti-ulcerogenic and gastroduodenal protective properties, and these properties may be attributed to, and therefore depend on, the mechanism of working of antioxidants (Das and Roy 2012; Madhu et al. 2012).

8.4.15 Wound-Healing Activity

The methanol extract obtained from *A. marmelos* was assessed for its wound-healing activity with intraperitoneal and topical administration on the incision and excision wound model with the help of injection and ointment, respectively. The application of methanol extract of the bael plant in injection and the ointment forms resulted in producing a considerable effect in both the wound types evaluated. The wounds treated with the bael plant extract in the excision model epithelialized quicker and the wound contraction rate was greater as compared to the control wound. The bael plant extract assisted in the healing process of wound as indicated by increased tensile strength of incision model. The results of wound-healing potential of *A. marmelos* were also consistent with results of wound-healing potential of a standard drug nitrofurazone (Jaswanth et al. 2001).

8.4.16 Toxicology

A. marmelos is generally considered as safe, as evidenced from the few studies performed to assess the toxicity of *A. marmelos* (Jagetia et al. 2003; Kruawan and Kangsadalampai 2006; Dhankhar et al. 2011). The fruit extract of bael plant recovered in water is considered as non-mutagenic to *Salmonella typhimurium* strain TA 100 (Kruawan and Kangsadalampai 2006). The pharmacological experiments carried out on animal models showed that the extract of fruits of *A. marmelos* when consumed at a dose concentration of 250 mg/kg body weight for the period of about 30 days does not have any adverse consequences (Dhankhar et al. 2011; Jagetia et al. 2003). Veerappan et al. (2007) collected the alcoholic (including methanol) and aqueous extracts of the leaves of bael plant in different concentrations and evaluated for its toxicity in experimental rats. *A. marmelos* extract dose administered at 50 mg/kg body weight concentration intraperitoneally for 14 days consecutively did not show any histopathological changes. The results of this study found that the extracts obtained from the leaves of bael plant have high margin of drug safety.

8.5 Conclusion

Bael (*Aegle marmelos* L.) is known to have numerous therapeutic and medicinal properties and its every part can find utilization. This necessitates large-scale cultivation of this plant particularly on unproductive land and wasteland. Production, postharvest management, and processing of bael is unorganized. This emphasizes its commercial management like other horticultural produce. Many studies have reported the bioactive compounds and health benefits of bael; however, further work is needed to establish the exact mechanism of action of bael with regard to many of its properties. Bael has tremendous potential to be processed for value addition in the form of different processed products, which will not only aid in providing functional foods to the consumers but also in increasing the returns to the growers. There is need to undertake research for improving the sensorial properties and particularly reducing astringency of bael fruit pulp. The health benefits and toxicology of bael is an area that requires attention of scientific fraternity. *A. marmelos*, in near future, can be exploited as a source of phytochemicals with proven therapeutic and medicinal properties in value-added products with successful commercial potential.

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Durian

9

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Abstract

In tropical Asia, Durian (*Durio zibethinus Murray*), a seasonal fruit has got its origin in the Malay Peninsula and is known as the King of the tropical fruits. The health-protective effect of durian fruit is largely concerned with the composition of the antioxidants and phenolic compounds. Durian fruit, belonging to the genus *Durio* and family Bombacaceae is also well known for its antimicrobial effects. Among the fruits, Durian has got a plentiful $n - 3$ fatty acids and helps in cholesterol reduction. Almost every part of the fruit, which could otherwise be wasted, is laden with a lot of potential in various fields. In this chapter, the various positive health benefits are discussed. Moreover, different antioxidants and their methods of characterization are explored. Nonetheless, durian fruit cultivation, export, and nutritional composition are also revealed.

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Keywords

Durian fruit · Health benefits · Antioxidants · Bioavailability · Antioxidant activity

9.1 Botanical Name and Common Name of Durian Fruit

Durian fruit-bearing trees belong to the genus *Durio* and family Bombacaceae. The durian has also been categorized in the family of Malvaceae as well as in the family of Durionaceae, consisting of only seven genera. The botanical name of the durian fruit is *Durio zibethinus*. The genus *Durio* consists of more or less 30 species, among which only nine species bear the edible fruits. Moreover, the durian fruits are sold locally except for the *D. zibethinus* (called as durian pertinent to their regions), which is marketed globally. Durian is an expensive and edible fruit in the region of Southeast Asia. Durian fruit occurs either in the wild or semi-wild form in South Tenasserim in addition to peninsular Malaysia and lower Burma. Durian is also known by names like *Kampung* Durian in English, *civet* fruit, and *Civet cat* fruit depending on the region of cultivation. Moreover, in China and Indonesia, durian fruit is known by Liu Lian and Dereyan, respectively, as their common names. In Borneo, these are commonly known as Dian, Durian Puteh, and Jatu (Tim 2012). The common names in some other languages are shown in Table 9.1.

Durian fruit may result in love or hatred sense toward itself within consumers, i.e., from devotion to revulsion. The famous naturalist Alfred Russel Wallace mentioned on durian: “the more you eat of it, the less you feel inclined to stop.” Durian fruit has a pungent smell described as “turpentine and onions, garnished with a gym sock,” which has triggered it to be banned from public places, public transports, and many hotels.

Table 9.1 Durian names in common languages

Language	Common names
Thailand	Thurian, Rian
French	Durion des indes
Portuguese	Durio
German	Durianbaum, Zibetbaum, stinkfrucht
Indonesia	Duren, Ambetan, Kadu
Philippines	Dulian
Spanish	Durian, durio, erizo de arbol
Cambodia	Thu-réén
Laos	Thourièn, Mahk tulieng
Vietnam	Sâù riêng
Mandarin	Liulian
Myanmar	Du-yin

9.2 Introduction

9.2.1 History of Durian Fruit

In the eighteenth century, G. E. Rumphius, a German botanist, in his book "*Herbarium Amboinense*" used the word "durioen," which is known as durian in the present era. G. E. Rumphius created the genus "durio" and Carl Linnaeus affixed the Latin name "*zibethinus*" to it. The term "durian" has been derived from a Malay word "duri" meaning "thorns." Alfred Russel Wallace, a world-famous naturalist, described the fruit as a custard containing butter and flavored with almonds and mixed with the flavor wafts of cheese like cream, brown sherry along with onion sauce. The fruit is harvested by allowing it to fall naturally, which is a characteristic of the fruit, rather than plucked like other fruits and this defines its best time for consumption.

D. zibethinus Murray is the parent species for all the Durian cultivars (Voon et al. 2007). The durian is believed to be originated from Borneo; thereafter, it spread to the Malay peninsula and some of the Indonesian islands during the pre-European times. Moreover, these fruits spread throughout the mainland by the Burma rulers to Ava and by the Europeans during the nineteenth century, which ultimately provided it a position in the list of major traded fruits in recent times (Blench 2008). According to the Department of Customs, 1991 report, Durian was the major fruit exported from Thailand in 1990, valued at $10 million. It is highly cultivated in Thailand and South Vietnam and to some extent in Southeast India, Malaysia, Ceylon, and New Guinea.

9.2.2 Production of Durian Fruit (India, World)

Indonesia, Thailand, Malaysia, and the Philippines are the major producers of Durian, which is a seasonal fruit, while North Australia, some South American countries, and Africa are the least producers, as shown in Table 9.3. The yield of durian fruit depends on the type of soil in which the plant is cultivated. For example one hectare in Thailand and Malaysia on average produces approximately 10–18 tons of durian fruit annually (Subhadrabandhu and Ketsa 2001). The fruit consisting of 20–30% of pulp depending upon the fruit variety despite foul smell has become popular in Asian countries due to its nutritional value. In addition to coconut and the papaya, durian is declared as a new source of agricultural wealth in the Malaysian National Agro-Food policy (2011–2020).

Durian grows best in a hot, humid, and wet climate with an average annual temperature of 24–30 °C, coupled with a relative humidity of 75–90% and in soils of a pH 5–6.5. Durian fruits get fully ripened and ready for the consumption in 2–4 days after falling from the tree and are highly perishable losing its eating quality in 5–6 days. Durian needs plenty of rainfall; however, a dry spell is necessary for the flowering stimulation and synchronization. Accordingly, durian best grows in lowlands as it faces the fruit production and growing problem on the high altitudes.

Table 9.2 Durian production (MT) in Malaysia, Thailand, and Indonesia (2013–2016)

Year	Thailand	Malaysia	Indonesia
	524,000.00	347,704.40	888.13
2013	569,000.00	373,082.90	759.06
2014	632,000.00	351,517.90	859.12
2015	602,000.00	368,270.70	995.73
2016	518,000.00	302,645.80	735.42

Source: multiple sources from national statistic publications

Durian fruit grows well enough in soils with a salinity of 0.02%; however, water logging is a growth-retarding factor for durian fruit causing diseases like fungal root and trunk rot (Tim 2012).

Durian tree needs a dry season for flowering (2–4 weeks) and wet weather for fruit ripening and is also greatly influenced by the seasons of the north-east and south-west monsoons. Due to wide acceptance, durian is sold worldwide even if the consumption is Asian market centric. Globally, Thailand, Indonesia, and Malaysia are the three top producers and exporters of durian fruit with their annual production of 800,000–900,000 (±600,000) metric tons for Thailand, 800,000–900,000 (±995) metric tons for Indonesia, and 800,000–900,000 (±350,000) metric tons Malaysia as depicted from Table 9.2. The Gulf of Thailand in the southeastern provinces of Chanthaburi, Rayong, Trat, and Prachinburi, the northern province of Uttaradit, and the southern provinces of Yala, Narathiwat, and Surat Thani reflect the main sites for fresh durian export. Likewise, Perak, Pahang, Johor, and Kelantan states are the major sites for durian fruit in Peninsular Malaysia.

The fresh durian fruit is supplied to local markets while the processed fruit in the form of paste or pulp to the export markets reflecting that the fruit is sold either in the fresh or processed form to mainly the Asian market and also to some non-Asian markets. Chantaburi in Thailand holds the World Durian Festival early May each year.

Among the processed form, pulp and paste after freezing are primarily utilized as ingredients by food processors, restaurants, and hotels. Table 9.3 depicts the trend of export value of fresh durian fruit to the world from the top three leading exporters from 2012 to 2016. The main varieties used for export are Golden Pillow (Monthong), Kanyou (Long Stem), and Chanee (Gibbon) from Thailand, Mountain Cat King (Mao Shan Wang/Musang King) and D24 (Sultan Durian) from Malaysia. One hectare in Thailand and Malaysia on average produces approximately 10–18 tons of durian fruit annually (Subhadrabandhu and Ketsa 2001).

The export and import trends increase accordingly as shown in Tables 9.3 and 9.4 whereby the import trend is also increasing every year. The total import from Thailand is approximately USD 693 million in 2016.

Unlike some other nonseasonal tropical fruits such as the papaya, which are available throughout the year, durian is a seasonal fruit that makes it a costly fruit, especially in off-seasons. For example, the price of some of the costly varieties of durian such as the D24 (*Sultan*), and Musang King (*Mao Shan Wang*) has reached

Table 9.3 Export value of fresh durian to the world (2012–2016)

Year	Thailand		Malaysia		Indonesia	
	USD	MT	USD	MT	USD	MT
2012	200,746,355	351,124,0.04	10,233,105	23521.022	4511	2.93
2013	243,094,716	367,056.61	11,638,890	20152.393	110	0.02
2014	387,258,988	369,602.48	10,169,717	13215.239	4966	11.01
2015	387,911,951	358,192.28	16,656,629	19891.629	1037	0.41
2016	495,196,132	402,660.50	17,927,300	17754.25	21,112	10.03

Source: UNCOMTRADE, 2018

Table 9.4 Import value (USD) of fresh durian in the world (2012–2016)

Year	China	Hong Kong	Singapore	France	Canada
2012	399,752,592	149,075,026	9,486,815	1,663,734	1,439,902
2013	543,165,444	168,891,401	8,544,650	1,312,040	1,408,249
2014	592,624,796	278,421,599	6,885,584	1,329,270	1,280,948
2015	567,886,361	324,672,302	8,915,544	880,367	1,094,009
2016	693,578,723	403,008,663	8,511,628	1,035,948	1,175,506

Source: UNCOMTRADE Databases, 2018

US$5–US$10 per kilogram in 2007 in Singapore. It is reported that the price of the Malaysian variety "Musang King" increased from 2 ringgit/kg to 60 ringgits/kg in 2018. The foul smell of durian fruit makes it unpleasant to carry in public and this has paved the way to the production of dried products out of it. Durian fruit in its dried form attracted the popularity in the market like mango and mangosteen. The attractive products of durian are in fried form in addition to the fruit in chips, toffee, and other snack forms. These processed products help to transport besides enjoying the taste of durian fruit in public, planes, and homes that is otherwise impossible.

Most of durian fruit produced in Malaysia is consumed in the fresh form, which necessitates durian import from Thailand particularly during durian fruit off season (April and May) in Malaysia. Thailand and Malaysia also import durian fruits to countries like Indonesia, the Philippines, and Brunei where the production is too low (Ketsa 2018).

India is currently the second-largest producer of fruits and vegetables in the world after China. During 2015–2016, according to the National Horticulture Database published by National Horticulture Board, India produced 90.2 million metric tons of fruits and 169.1 million metric tons of vegetables. The area under cultivation of fruits stood at 6.3 million ha while vegetables were cultivated at 10.1 million ha. However, India does not contribute enough to the durian production and Kerala is the largest durian producing state. In India, the production of durian fruit limited to the domestic market. British in the Nilgiris first introduced the durian plant in India and the fruit is called the "king of fruits" in Southeast Asia. Berlayar and Kateri regions of Palakkad districts contribute enough to the annual production of durian fruit in India. In India, durian fruit due to its limited production is sold at Rs. 1000/kg.

9.2.3 Botanical Description of Durian Fruit

Durian fruit is known by its botanical name of *D. zibethinus*, derived from "*duri*" (Malay origin) meaning "*thorn*" and "zibenthinus" (Indian civet (*Viverra zibetha*)) meaning foul odor of the fruit. The botanical tree of Durian is presented in Table 9.5.

The shape of durian fruit varies according to the species from round to oblong. The color of the husk lies between green to brown while the flesh varies from pale yellow to red color and has a sulfur and onion-like odor. Morphologically, the fruit is bestowed with a large size. It has a 30 cm length and 15 cm diameter dimensions, a unique odor, a shell with formidable thorns, and a weight of 1–8 kg range (Voon et al. 2007). The trunk of the Durian tree is short, straight, rough, and peeling type with a diameter of 1.2 m, coupled with a canopy of coppery or gray scaled rough branches and thin branchlets forming an umbrella over the trunk. In tropical forests, the Durian tree can touch a height of 120 ft (approximately 36.6 m). It takes 5–7 years for a durian tree to be fully matured. The flowers are very fragrant, produced twice in a year, and sustain on the tree only for a day during which they fall off after pollination by birds and bats attracted by nectar, which finally results in a fully ripe melon-shaped fruit approximately 3 months after pollination. The propagation of the fruit occurs through propagation, grafting, and budding in addition to the propagation through the dispersal of seeds by birds or wildlife after consuming the fruit for nutrition.

During the whole year, durian tree contains the round based, or elliptic and oblong leaves emerging alternately on the tree. These leaves are evergreen, more or less leathery and pointed at the tip. The upper side of the leaf is dark-green and glossy in touch compared to the lower side, which has a silver or pale-yellow color, coupled with a dense covering with a hairy-jacketed scales having grayish or reddish-brown color. Moreover, durian fruit has a tough, thick, and semi-woody rind or shell yellowish green in color and contains dense sharp-pointed spines. In addition, the fruit internally consists of five slots holding the flesh creamy white, yellowish, pinkish, or orange in color coupled with one to seven chestnut-like seeds.

Table 9.5 Botanical tree of durian

Species	*Durian zibethinus*
Gender	Durio
Tribe	Durioneae
Subfamily	Helicteroidee
Family	Bombacaceae
Order	Malvales
Superorder	Rosanae
Class	Magnoliopsida- dicotyledons
Division	Magnoliophyte- flower plants
Superdivision	Spermatophyte- seed plants
Subkingdom	Tracheobionta- vascular plants
Kingdom	Plantae- plants

In durian fruit, the flesh that is the only part eaten as edible part contributes to 33% of the total fruit. The seeds constituting about 20–25% and the shells are not edible and hence discarded, and as a result of every year, a major portion of the planted durian fruit is wasted. However, these wastes are converted to various important products (Amid and Mirhosseini 2012). Durian fruit cultivar is also called as “king of fruits” is derived from the *D. zibethinus* in the Malay Peninsula and has an exceptional taste and aroma. Some of the Southeast Asian countries more importantly Malaysia, Thailand, Philippines, and Indonesia are the main hubs for the growth of this seasonal tropical or climacteric fruit (Srianta et al. 2012).

Durian fruit has an outer green to brown spiky skin. The sweet flesh that is the edible portion of the fruit is somewhat yellow, white, golden yellow, or red in color. Most of the durian fruit varieties are having flesh with pleasant and attractive color. Ang Heh (Red Prawn Durian having round-shaped and shorter spines with a skin color of golden chocolate), Chaer Phoy-15 (Green Skin Durian), and Khun Poh are some of the popular cultivars of durian fruit. Durian varieties have a characteristic taste, mouthfeel, and color of the flesh, such as a *sweet*, highly aromatic, fruity-like taste, soft texture, and yellow to creamy flesh color of Ang Heh cultivar compared to a *less sweet*, a bit harder texture, and white to cream flesh color of Chaer Phoy-15. One more variety called as *bitter to sweet* taste has a strong aroma with golden yellow flesh color of Khun Poh cultivar (Ho and Bhat 2015). An earlier study by Berry (1980) revealed that a thin and light brownish covering engulfs the seeds and is embedded inside the flesh.

Durian fruit has a suture or a little gap between the two locules. The opening and dehiscence along the suture caused coupled with shrinkage due to the water loss from the tissue is a major problem in the postharvest scenario. This dehiscence reflects the consumer’s preference of the fruit such as a less ripe fruit with a relatively firm pulp texture and the milder scent is preferred in Thailand and a fully ripe fruit devoid of splitting is preferred in Singapore (Sriyook et al. 1994).

Durian fruit is very rich in minerals, dietary fibers, sugar, vitamin C and P, K, Ca, Mg, Na, Fe, Mn, Cu, and Zn (trace elements). Compared to other fruits, durian is rich in carbohydrates, proteins, fats in addition to tryptophan (a serotonergic amino acid) and $n - 3$ fatty acids. The antioxidant properties coupled with fatty acid composition bestow durian fruit with health benefit properties. Among the various cultivars of durian fruit, Mon Thong cultivar is the highest source of polyphenols, quercetin, flavonoids, flavonols, tannins, anthocyanins, ascorbic acid, and carotenoids (major bioactive compounds) (Dembitsky et al. 2011).

A polysaccharide gel from *D. zibethinus* Murr. cv. Mon Thong entraps the lipids, thereby controlling the lipid levels in patients when incorporated in their diet. Moreover, antipyretic properties are also reported from the decoction product of leaves and roots (Tippayakul et al. 2005). Nonetheless, Dembitsky et al. (2011) explored the cholesterol reduction and immune response reaction properties of the polysaccharide gel extracted from durian fruit hulls. Mon Thong durian variety of durian fruit contains the highest quantity of antioxidant phytochemicals and is therefore preferred among all the varieties (Gorinstein et al. 2011).

The amount of bioactive compounds present is determined by the stages of ripening in the fruit. Polyphenols and flavonoids are present in higher amounts in the overripe fruit that bestow them the highest antioxidant activity. However, the ripe fruit is a rich stock of quercetin, ascorbic acid, and anthocyanins, and in mature fruits, tannins are found in the highest content. Durian fruit in the ripe stage consists of excellent antioxidant and health-protective compounds that protected the cholesterol-fed rats from liver and heart diseases (Leontowicz et al. 2011).

9.2.4 Composition and Nutritional Value of Durian Fruit

According to a recent research of The Swiss Society of Food Science and Technology, in comparison to the fruits that are almost equal in ripeness such as lychee, mangosteen, and mango grown in Asia, durian is a rich source of antioxidants. However, durian has some adverse health impacts to consumer especially pregnant women, diabetic patients as well as obese people if consumed in large quantities. Dr. Patrick Chia (a fetal medicine specialist in Malaysia), suggested women to consume durian during the period of pregnancy. However, durian fruit has a high content of sugar in it due to which the women suffering from gestational diabetes should avoid eating this fruit. Moreover, durian fruit has high glycemic index, that may lead to overweight of the fetus if consumed in the last trimester by a pregnant lady. This fruit is also not suitable for obese persons due to the fact that durian fruit is a rich source of fat and has three times more energy than other fruits. The nutritional value of durian fruit is shown in Table 9.6.

9.3 Antioxidants Properties

Fruits and vegetables have received a large preference to be explored due to the fact of being the unconstrained stocks of natural antioxidants and dietary fiber. Owing to natural antioxidants, vitamin C, carotenoids, and polyphenols (Ness and Powles 1997), fruits and vegetables combat the cell-damaging effects of free radicals (Prior and Cao 2000). Some of the important bioactive compounds of durian fruit are depicted in Table 9.7 with their antioxidant value in Table 9.8.

Consequently, seasonal fruits are the most important fruits in tropical Asia with potential health benefits and antioxidants. Durian (*D. zibethinus*) derived from *D. zibethinus Murray* (originating in the Malay Peninsula) is one of them (Voon et al. 2007; Arancibia-Avila et al. 2008) with high nutritional and bioactive properties due to flavonoids, flavonols, and total phenolics. Durian fruit consumption runs parallel with the stages of fruit ripening according to the consumer's preference, which thereupon determines the bioactive and antioxidant compounds ingested. Among different stages of durian fruit ripening, ripe and overripe stages represent the stages of highest contents of polyphenols, flavonoids, flavonols, tannins, vitamin C, and antioxidant capacities (Paśko et al. 2019). More precisely, Arancibia-Avila et al. (2008) revealed that ripe durian has a higher content of total

Table 9.6 Durian fruit: Nutritional value

Nutrient	Value per 100 g
Water content	64.99 g
Energy	147 kcal
Protein content	1.47 g
Lipid content	5.33 g
Ash content	1.12 g
Carbohydrates	27.09 g
Total dietary fiber	3.80 g
Calcium (ca)	6 mg
Iron (Fe)	0.430 mg
Magnesium	30 mg
Phosphorus	39 mg
Potassium	436 mg
Sodium	2 mg
Zinc	0.280 mg
Copper	0.207 mg
Manganese	0.325 mg
Vitamin C	19.7 mg
Thiamin	0.374 mg
Riboflavin	0.2 mg
Niacin	1.074 mg
Pantothenic acid	0.230 mg
Vitamin B-6	0.316 mg
Folate, total	36 µg
Vitamin B-12	0 µg
Vitamin A, RAE	2 µg
Retinol	0 µg
Carotene, beta	23 µg
Carotene, alpha	6 µg
Cryptoxanthin	0 µg
Vitamin A, IU	44 µg
Cholesterol	0 mg

Adapted from Ness and Powles (1997)

polyphenols and flavonoids as compared to mature and overripe. Durian in the immature stage has strong cytotoxic effects on $HepG_2$cells and hence durians can act as medicinal as well as functional foods.

9.3.1 Antioxidant Properties of Durian Fruit

It is reported that carotenoid antioxidants of fruits and vegetables play an important role in promoting human health. The quality of fruit and fruit products is determined on the basis of carotenoids and other antioxidants (Lee and Castle 2001). Durian fruit consists of a large number of phenolics, carotenoids, and flavonoids. Durian is an

Table 9.7 Durian fruit: Bioactive compounds

Compounds (on fresh weight of durian pulp)	Unit	Value
Flavonoids	mg catechin/g	1.523 ± 0.17
Flavonols	μg catechin/g	67.05 ± 3.1
Anthocyanins	mg cyanidin-3-glucoside/g	17.12 ± 1.1
Vitamin C (Ascorbic acid)	mg ascorbic acid/g	5.65 ± 0.2
β-Carotenoids	μg/g	4.94 ± 0.2
Polyphenols	mg gallic acid/g	2.58 ± 0.1
Total carotenoids	μg/g	7.26 ± 0.4
Tannin	mg catechin/g	1.37 ± 0.1

Adapted from Arancibia-Avila et al. (2008)

Table 9.8 Durian fruit: Antioxidant (a/o) value of bioactive compounds

Compound	Unit	a/o value
ORAC (oxygen radical absorbance capacity)	μmol Trolox equivalents/100 g	1838
Lipophilic antioxidants		
Carotenoids (total)	mg carotenoids/100 g	306
Vitamin E homologues (*Total*)	mg of vitamin E/100 g	4800

Adapted from Isabelle et al. (2010)

important fruit because of its valuable health benefits linked to the composition and the antioxidants properties of the fruit (Leontowicz et al. 2008; Ashraf et al. 2010). A product from the fruit hull called polysaccharide gel helps in the cholesterol reduction in addition to its reaction to the immune responses. Studies have shown that in comparison to papaya and pineapple, durian fruit lowers the glycemic index largely. Durian is rich in $n - 3$ fatty acids, in comparison to most other fruits.

9.3.2 Antioxidant Properties of Fruit Juices

Juice is the product made after crushing the fruit pulp by various methods. Chingsuwanrote et al. (2016) prepared the fruit extract of Chanee and Monthong cultivars of durian (*D. zibethinus* Murray) and Sichompu and Rongrien cultivars of rambutan (*Nephelium lappaceum* Linn) by mixing vigorously along with 90% ethanol (30 mL) for a time period of 2 min, thereafter sonicating the extract for 10 min in an ultrasonic bath. Among the various cultivars of durian, Monthong cultivar extract is bestowed with higher antioxidant as well as anti-inflammatory activities compared to Chanee cultivar. Among the antioxidants present in the durian fruit juice, the prominent ones are vitamin C, phenolics, flavonoids, and carotenoids. Moreover, caffeic acid and quercetin represented as the dominant ones among the antioxidants in four varieties of durian, namely, D11, Chaer Phoy, Yah Kang, and Ang Jin (Ashraf et al. 2010).

9.3.3 Antioxidant Properties of Durian Seed

Durian seeds can also be a potential source of antioxidants. However, a limited research has been done till date to elucidate the antioxidants in durian seeds. The antioxidants from durian seeds can be extracted by using acetone and water in the ratio of 7:3 (weight:volume) (Liu et al. 2013). This study revealed that durian seeds contain mostly oligomeric proanthocyanidins (OPCs) as antioxidants. However, the OPC content of durian is much lower than in the mangosteen pericarp, cocoa, and grape seeds. In addition, durian seeds contain some complex secondary metabolites that can be used as a source of epicatechin derivative preparation, which can show more antioxidant activity than the epicatechin itself. Hence, rather to discard as wastes, durian seeds can be potentially used in preparation of value-added food ingredients. In a recent study, durian seed extracts containing bioactive compounds were found to cause Herpes simplex virus type 2 (HSV-2G) inhibition due to the antioxidants present in it (Nikomtat et al. 2017). Nonetheless, durian seeds are bestowed with some secondary metabolites that are novel in function and have less than 500 as molecular weight. A recent study has found that due to the higher moisture content of durian fruit pulp than durian seed, the total phenolic contents in durian seed extracts are higher than in pulp extracts (Toor and Savage 2005).

9.3.4 Antioxidant Properties of Fruit Peel

Durian fruit peel can be used as an important antioxidant source. A number of studies have revealed the antioxidant activity of the durian peel. Ethanolic extracts of the durian fruit peel were used for the determination of antioxidant activity by Muhtadi et al. (2014) compared to a standard vitamin E and determined for their free radical scavenging properties. The results showed that the peels of durian fruit (*D. zibethinus Murr*ay) consist of IC_{50} value of 28.83 μg/mL. The antioxidant compounds that are present in the durian fruit peel are 4,4-dimethylporiferasta-18 (19)-en-3-ol and 3α-E-ferulyloxy-lup-20(29)-en-28-oic acid.

9.3.5 Antioxidant Properties of Fruit Wastes

One of the main sources of municipal waste is contributed by the fruit wastes. Among fruit wastes, durian fruit is an important contributor. The durian fruit wastes are mostly constituted of seed and peel that have been already discussed in the previous sections.

9.4 Characterization of the Chemical Compound(s) Responsible for Antioxidant Properties of Durian Fruit

The method used for the characterization of the bioactive compounds from durian fruit was described by Ashraf et al. (2010). Fruit samples are first mixed with dichloromethane: pentane (1:1 v/v) in a 1:2 proportion (1 kg: 2 L solvent mix) for at least 48 h at 4 °C. Evaporation under a vacuum of the solvent obtained through decantation is done at 50 °C at 50 rpm. Total phenolic content, total flavonoids, carotenoids, vitamin C are the prominent ones among the bioactive compounds present in durian fruit whose characterization is discussed briefly.

9.4.1 Total Phenolic Content

A ripe durian fruit contains a total polyphenol content in the range of 21.44–374.30 mg gallic acid equivalent (GAE) per 100 fresh weight (FW). Total phenolic content is determined by a method described by Folin-Ciocalteu (Liu et al. 2002). One milliliter of juice extracted with 9 mL of 80% methanol for a duration of 30 min at 25 °C. Then 1 mL of aliquot after centrifuging at 4000 rpm for 10 min is diluted with 80% methanol extracts and added to 25 mL volumetric flask containing 9 mL distilled water to which Folin-Ciocalteu phenol reagent (0.5 mL) is added and mixed. Na_2CO_3 solution is then mixed and left for about an hour. The absorbance is measured at 750 nm against the blank sample and the results are quantified in terms of grams of gallic acid equivalents (GAE).

9.4.2 Total Flavonoid Content of Durian

The total flavonoid content in durian fruit is estimated by the method followed by Sultana in which the extract obtained after placing 2.5 g of sample in Soxhlet extractor by refluxing it with methanol for 2 h at 80 °C and evaporated in a rotary vacuum evaporator at 40 °C. After this, the extract is mixed with 0.3 mL of 5% $NaNO_2$ and kept for 10 min at room temperature. The absorbance is measured at 500 nm and the total flavonoid content is expressed as catechin equivalents (CE) (Singleton et al. 1999).

9.4.3 Total Carotenoids Content of Durian

For the determination of total carotenoids, the method used by Lee and Velioglu is followed (Lee and Castle 2001: Velioglu et al. 1998). In this method, 5 g of sample is mixed with 50 mL of *n*-hexane–acetone–ethanol (v/v/v, 2:1:1) which is then placed in flask and the extract (obtained on a shaker at 200 rpm for 20 min at room temperature) is centrifuged at 4000 rpm for 10 min at 4 °C on a shaker at 200 rpm for 20 min. Centrifugation leads to the separation of the liquid into two layers, an organic layer and an aqueous layer. Finally, the total carotenoid content is measured at 450 nm and expressed as β-carotene equivalents.

9.4.4 Vitamin C Content of Durian

Vitamin C content is determined by following the method used by Özyürek et al. (2007). One milliliter of Cu(II)-neocuproine placed in ammonium acetate which contains a medium at pH 7 is mixed to 1 mL of the extract obtained from the durian fruit. After mixing the whole mixture vigorously, bis-(Nc)–copper (I) chelate is formed and the absorbance is measured at 450 nm, which gives the ascorbic acid content. The ascorbic acid finally gives the vitamin C content.

9.4.5 Antioxidant Activity of Durian

Durian fruit is reported as being bestowed with the important property due to antioxidants that include numerous health benefits. Among the different solvents used for the extraction of the bioactive compounds, methanol is the most effective solvent on an extraction yield basis (Haruenkit et al. 2010). The various antioxidants present in the durian fruit include polyphenols, flavonoids, flavanols, tannins, and ascorbic acid whose antioxidant activity is of great importance and has been determined by a number of reported methods (tests), among which some are briefly discussed.

9.4.5.1 Cupric Reducing Antioxidant Capacity (CUPRAC) Method

This type of test is done following the method described by Apak et al. (2004). In this method, copper (II)–neocuproine [Cu (II)–Nc] reagent is used as a chromogenic oxidizing agent. To determine the activity, Nc and NH_4Ac buffer solution, durian solution extract, and water are added to 1 mL of Cu (II). The final volume of the solution is made up to 4.1 mL. Durian extract is taken as the standard solution. Finally, the absorbance is recorded against a reagent blank.

9.4.5.2 DPPH Method

This method is more common to determine the antioxidant activity as described by Ozgen et al. (2006). In this method, the sample extract (0.1 mL) is mixed vigorously with 1,1-diphenyl-2-picrylhydrazyl (DPPH) solution (3.9 mL, 25 mg/L) in methanol. The stable absorbance is finally recorded at 515 nm.

9.4.5.3 FRAP Assay Method

This method of ferric reducing antioxidant power (FRAP) is based on the ability of the reduction of the ferric-tripyridyltriazine (Fe^{3+}-TPTZ) to a ferrous form (Fe^{2+}) by the antioxidant compound. Here the absorbance is measured at 593 nm (Szeto et al. 2002; Ozgen et al. 2006).

9.5 Health Benefits of Durian Fruit

Durian fruit is bestowed with numerous benefits, including health benefits due to the presence of vitamins and minerals such as vitamin A, C, B_6, riboflavin, thiamin, iron, niacin, zinc, potassium, phosphorous, calcium, and magnesium. Durian fruit is a rich source of phytonutrients, water, protein, and beneficial dietary fiber that makes it beneficial to health of human in one way or the other. Durian fruit helps to lessen joint inflammation in human body in addition to overcome the problems of depression. It helps to maintain the thyroid health and reduces the headache, stress in addition to the reduction in anxiety.

Moreover, durian fruit is also a fair source of energy. It is reported that about 130–253 kcal energy (same as energy provide by one pair+ four peeled apples) is provided by consuming one serving (approximately 155 g) of durian aril (Belgis et al. 2016). Durian fruit can also be a good source of micronutrients, dietary fiber, sugar, fat, and bioactive compounds. Durian has numerous health benefits, including the digestion and immune system improvement, premature aging, cardiovascular diseases and cancer prevention, and stabilization of free radicals. It also helps in lowering blood pressure and strengthening bones. Its energy giving property can also be credited to the fat and sugar. Digestion in the body is facilitated by the consumption of durian fruit along with the reduction in blood pressure, aging, and anemia. Hence, durian fruit could be an alternative for the complete diet for body. It also diminishes the risk of cardiovascular diseases, insomnia. Studies have revealed that sexual dysfunction, cancer, bone-related problems can be prevented by durian consumption. Like any other fruit, durian fruit too has some disadvantages causing illness that do not encourage people to consume durian fruit in excessive amounts.

Durian fruit has innumerable health benefits. Some of the worth mentioning health benefits are mentioned below.

9.5.1 Effects of Durian on Blood Glucose Level

Durian helps to bring down the glycemic index in the human body due to the presence of fat and fiber. Studies have revealed that durian has more potential to decrease the blood sugar level, i.e. having a lesser glycemic index (GI) value than watermelon, papaya, and pineapple. The problem of increased glucose level occurs due to the conversion of carbohydrates to glucose. Fiber, present in durian fruit, helps to slow down digestion, thereby the conversion of carbohydrates to glucose is retarded and finally results in a reduced glycemic index (GI) value. The fat present in the durian fruit also helps in reducing glucose absorption, thereby decreasing the blood sugar level. GI-related effects of durian fruit are still in its initial stage and need further concern.

9.5.2 Effects of Durian on Cholesterol

Durian fruit is also very helpful in controlling the levels of cholesterol (Leontowicz et al. 2011). In the human body, it is revealed that durian causes the cholesterol level. Moreover, it helps in reducing the postprandial plasma. Durian extract incorporation in the diet helps to combat total cholesterol and low-density lipoprotein cholesterol level, which are harmful to health otherwise. Research has shown that harmful triglycerides are reduced to a large extent by the consumption of durians with diet. Cholesterol and free fatty acids can be inhibited by three propionate esters, namely, ethyl propionate, methyl propionate, and propyl propionate.

9.5.3 Antiproliferative Activity of Durian Fruit

Durian fruit constitutes polyphenols which bestow the fruit with the antiproliferative property activity. Polyphenols are witnessed to decrease or quench reactive oxygen species (ROS) in our body as it forms stable phenoxyl radicals through accepting a single electron which then disrupts the chain oxidation reactions (Gorzynik-Debicka et al. 2018). Polyphenols are active in the range of 21.44–374.30 mg GAE that reflects the amount of antioxidants and their antioxidant activity. Also, research has revealed that polyphenols can induce apoptosis and could be used for the cancer growth inhibition (Borska et al. 2012: Singh et al. 2011). In addition, research is with the opinion of polyphenolic compounds playing an important role in their property of antiproliferative activity, which is of course bestowed due to the regulation of epigenetic modifications (Stefanska et al. 2012). Polyphenols in durian fruit are antiproliferative in action, this has been also reported by Jayakumar and Kanthimathi (2011) from their study on the breast cancer cell line (MCF-7).

9.5.4 Probiotic Effects of Durian Fruit

Durian aril has a moisture content range between 3.10 and 19.97 g/100 g fruit weight coupled with a pH of 6.9–7.6 that makes it feasible for the process of fermentation by bacteria during storage. Lactobacillus strains lead to the production of exopolysaccharide (EPS) which is a good component to show the useful probiotic effects coupled with a reduction in cholesterol and also with positive effects on gastrointestinal (GIT) microbiome. From the fermented products, Tempoyak has good probiotic properties and is used as a seasoning in cooking. The various microorganisms found in durian fruit that make it a potent probiotic diet are *Lactobacillus plantarum*, *Lactobacillus fersantum*, *Lactobacillus corynebacterium*, *Lactobacillus brevis*, *Lactobacillus fructivorans*, *Lactobacillus mali*, *Lactobacillus fermentum*, *Lactobacillus durianis*, *Lactobacillus casei*, and *Lactobacillus collinoide*s.

Durian is mostly consumed fresh and its flesh is consumed directly and is highly nutritious. The other forms in which durian fruit is consumed includes a dish made of durian fruit and sticky starch. Durian fruit is also used in bakery products. Because of the low shelf life of durian fruit, a product called "tempoyak" is made out of the fruit by the process of fermentation. Durian can also be converted into a highly tasty dish called "lempok" which is made after boiling the durian flesh with coarse sugar. These all products made out of the durian fruit by fermenting the fruit help greatly to retain the characteristic flavor of the fruit. Also, some other products out of the durian pulp include the durian dried powder, durian leather, and durian chips (Jaswir et al. 2008; Jamradloedluk et al. 2007) for their commercialization and shelf life enhancement.

In the markets, durian is sold as cut open, divided into pieces or even as a whole. It is also cooked in coconut water or simply with sugar water. Durian flesh is also consumed with ice and syrup and even with rice. Durian flesh is also smoked to produce a special dish in Palembang while it is also used as a sauce in combination with rice that is preferred by the Javanese residents. Sometimes durian flesh is mixed with pumpkin in Bangkok. Green and young durian leaves are also cooked. Not only the flesh and leaves but also the seeds are consumed after processing operations like frying, drying, or boiling. Durian seeds are also consumed in confectionary especially in Java. A side dish is also made of the durian seeds after drying and frying with spices in coconut oil. Durian rind ash after burning is also used to make special cakes.

9.6 Conclusion

Durian is a treasure of macro- and micronutrients such as sugar, fat, volatile compounds, bioactive compounds, potassium, and dietary fiber. Durian fruit represents an important source of antioxidants that exhibit multifarious effects in the protection of the human body. Moreover, Durian fruits are having wide applications in food industries because of the trendy health-conscious consumer behavior. The antioxidants in Durian fruit present an in vitro health benefits contrary to synthetic antioxidants among which cholesterol and blood level reduction are prominent. Moreover, it has got more health-promoting antioxidants compared to most of the fruits that help to combat cancer, cardiovascular diseases, blood pressure, and in strengthening of bones. In addition, durian can be used for the manufacture of a number of traditional foods consumed for the health aspects. Finally, the various bioactive components from the durian could also be used in the shelf life extension of various foods after incorporation.

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Sapota

10

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Abstract

Sapota or Sapodilla is a climacteric fruit, generally utilized for its sweet and delicious fruits. It contains a substantial quantity of vitamins, minerals, proteins, ascorbic acid, polyphenols, etc. In particular, a rich variety of phenolic compounds (as sources of natural antioxidants) and flavonoids have attracted the attention of many researchers and practitioners toward this fruit. Increased incidence of the diseases such as CVD, diabetes mellitus, and cancer is associated with the socioeconomic burden and higher cost for public health systems. Therefore, an allopathic alternative is required having minimum risk factors, mainly antioxidants are utilized for disease prevention. So, sapota is one such fruit, rich in polyphenolic content and thus having high antioxidant activity, which could be isolated for addition into other products and medicines. Thus, the chapter discusses about the important bioactive compounds present in sapota fruit and other different botanical fractions and their associated health benefits.

Keywords

Sapota · Polyphenols · Vitamins · Antioxidant activity · Health benefits

10.1 Introduction

10.1.1 History

Manilkaraachras (Mill) Fosb., syn *Achrassapota* L., Sapodilla

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Sapota fruit is a native to Mexico in the Tropical America although it has extended to Asian countries like Sri Lanka, India, Philippines, and Malaysia where it has been accepted extremely well (Chadha 1992). The fruit was first introduced in India in Gholwad village of Maharashtra (Jadhav 2018a, b). It is also known by various synonyms such as chiku, ellupai, zapota, dilly, and sapodille. In the colonial times, the Spanish carried it to Philippines from where it got adopted everywhere in the tropic world. From Philippines, it was distributed all over Southeast Asia as a popular tree fruit, where it was both consumed and exported. In 1802, it reached Sri Lanka and in 1898, India. It is believed that it belongs naturally to Yucatan as well as to the parts near to southern Mexico, northern Belize, and north-eastern Guatemala. It is believed to be cultivated throughout tropical America, Southern part of Florida mainland, and the West Indies.

Sapota is also utilized as a traditional medicine in India. Fruits of sapota plant are freshly eaten preferably when ripe; also, this fruit is good amalgamation of various types of acids, sugars, protein, phenolics, carotenoids, vitamins (A, C, niacin, folate, pantothenic acid), and minerals (K, Cu, Fe). It is a good source of dietary fiber and ascorbic acid, thus show higher antioxidant properties. Thus, these inferences Unite to strengthen the idea that sapota is deemed to be one of the healthiest fruits to alleviate micronutrient malnutrition (Srivastava et al. 2014).

10.1.2 Production (India, World)

At present, numerous species of sapota were cultivated in the countries like India, Thailand, Philippines, Africa, Malaysia, and in most of tropical countries worldwide (Milind and Preeti 2015). Overall production of sapota in India in 2016–2017 was reported to be 1284.60 metric tons in an area of 107.16 ha. In India, the leading states in the production of sapota are Karnataka, Gujrat, Maharashtra, Tamil Nadu, and Andhra Pradesh. It has been reported that in the year 2016–2017, Karnataka is the highest sapota producing state in the country with production of 350.33 metric tons in an area of 29.99 ha, followed by Gujarat with 325.15 metric tons in an area of 29.56 ha (Horticulture Statistics Division, Department of Agriculture). In Gujarat, it is grown on area of 25,000 ha with an annual production of 2.36 lakh metric tons, whereas in south Gujarat, the area under sapota cultivation is 14,000 ha with 1.36 lakh tons annual production (Anon. 2007) and its cultivation is mainly concentrated in Valsad, Navsari and Surat districts (Jadhav 2018a, b). Sapota is exported primarily to countries like United Arab Emirates, Bahrain, Oman, Qatar, Saudi Arabia, Canada, the United Kingdom, Singapore, Kuwait, United States, and others. Total export in the year 2018–19 turned out to be 1423.62 metric tons (Fig. 10.1).

In Gujrat, the production of sapota has been an important part in enhancing the socioeconomic status of the big and marginal farmers. Sapota production has been undertaken commercially in Gujrat, as the crop is considered as certain and consistent economically and the marketing has also been improved that has enhanced its production. The area under this crop has increased quickly and it is probable to rise

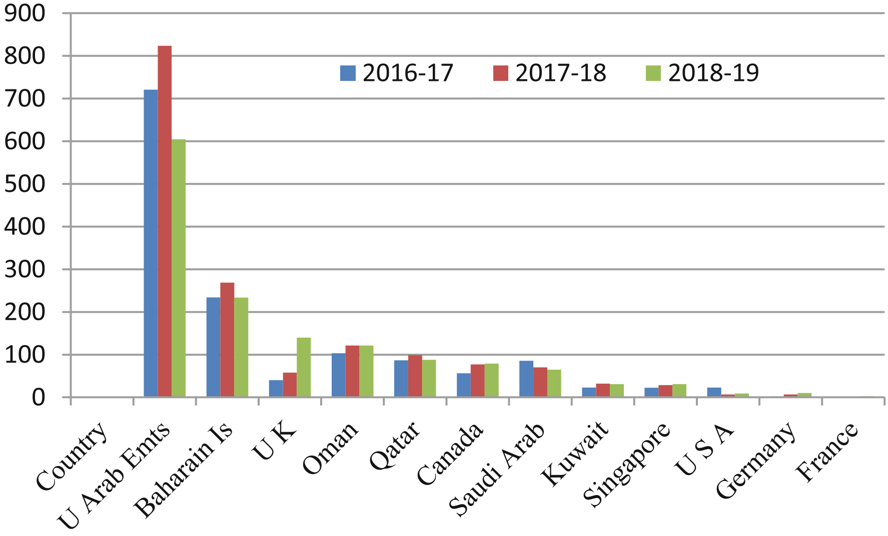

Fig. 10.1 Export of sapota from India to other countries. (Source: APEDA Agricxchange 2018)

in the future as well. But with the increase in the production, the fruit disposal becomes difficult during the peak season as the fruit production has increased, the disposal of fruit at reasonable rates during peak harvesting season becomes difficult, then the farmers are forced to sell their valued produce at very inadequate price.

The plant is usually cultivated in the tropical areas, however, sometimes it is also grown in semitropical areas in a greenhouse environment. It usually grows up to 1200 m above sea level. It requires a warm temperature of 10–38 °C with a relative humidity of 70% for its growth due to its tropical nature. Finest environment for the growth of sapota includes soil systems of alluvial, medium black soil, sandy loam, and red laterite, along with pH acidic to neutral. Fertilizers that contain 2–4% phosphoric acid, 6–8% nitrogen, and 6–8% potash are to be utilized every 2–-3 months for a good yield (increasing gradually to 250 g per plant). Plant requires a very little pruning and it should be shielded from frost. Commonly, the propagation of sapota is by seeding and grafting. Germination readily occurs within the seeds whereas the growth is slow as it takes almost 5–8 years. The seeds may remain viable for several years. Vegetative propagation is a better choice in this matter as it can help to achieve uniformity of planting material as well as avoids the deceleration of growth of seedling trees. It is hard to tell about the maturity of the fruit just by seeing; however, if any change of color is observable, then change of color from yellow to brown could be a major parameter for maturity. Underdeveloped flavor and sweetness could be easily seen in the immature harvested fruits. So, for maturity estimation, the coat of the fruit is rubbed to check if it readily loosens or the scurf could be removed with ease without the leakage of latex part or easily without leaking of latex. Fruits picked up following the above parameters, though completely mature, can be hard so for the few days should be kept at room temperature to soften (Milind and Preeti 2015).

With the maturation of the fruit, an increase in the reducing sugars concentration and a decrease in tannin content and total acidity can be observed. It has been reported that the fruit without pedicel was found to be rotten after the 7th day whereas the fruit with pedicel remained acceptable for intake until 14th day. However, the partially ripened fruits showed similar behavior in case of weight retention in both the cases (with or without pedicel). Manual removal of the pedicel could result in mechanical injuries to the fruit, which in turn hastens the ethylene production, can cause infestations, and results in an early senescence. However, it was witnessed that the use of scissors for removal of pedicel results in an enhancement of fruit quality. The conditions during the storage of fruits do influence the characteristics of the fruit. It has been reported that the refrigerated storage of partially ripe fruits resulted in higher weight retention than the fruits kept at ambient conditions (Brito and Narain 2002).

The sapodilla tree is a slow growing evergreen tree with a widespread root system. At young age, the tree has a definite pyramidal shape; however, it may develop a dense as well as round crown with age that may be irregular or open in shape. The tree is rich in gummy white latex called chuckle. The tree could grow up to a height of 100 ft in the tropics, however, the grafted cultivars are comparatively shorter (Jadhav 2018a, b). Being a climacteric fruit, it undergoes rapid ripening changes within 5–7 days after harvesting, during which the fruit becomes soft, sweet, and develops excellent aroma with decline in tannin content, latex sapotin, aldehydes, and acidity. These changes are associated with increase in the activities of enzymes like catalase and peroxides (Chadha 2001). Owing to these rapid biochemical changes, the sapota fruits have very poor shelf-life as compared to many other climacteric fruits.

There have been many researches related to the delay of ripening process. It has been recommended that 2,4-dichloro-phenoxy acetic acid, wax coating, kinetin (100 ppm), or silver nitrate (40 ppm) could be utilized to retard the process of ripening in case of sapota fruit; however, 2-chloroethyl phosphonic acid (Suryanarayana and Goud 1984) and ethylene (Sastry 1970) were found to hasten the process. Also, it has been suggested that packaging in polyethylene bags results in weight loss reduction up to 50% in case of fruit (Kumbhar and Desai 1986). Sapota fruit's shelf life depends on various factors such as the conditions during the storage of the fruit such as humidity, temperature, ripening stage, variety, and the rate of respiration (Yahia 2004). Any variations in the shelf life are dependent on the changes in these factors. Gibberellic acid is recognized for extension of shelf life of sapota fruit, reduces the softness of the fruit as well as the shrinkage of fruit (Kumbhar and Desai 1986). It has been claimed by Singh (1969) that shelf life of the fruit could be improved by storing the fruit at 3–5 °C and 85–90% RH (up to 8 weeks).

Previously it was suggested that 5–10% carbon dioxide is known to delay the process of ripening and could also remove ethylene from storage conditions (Yahia 1998). However, the use of carbon dioxide is not recommended now as higher concentration may damage the taste and appearance. Temperature of 14 °C ± 1 °C with RH of 90–95% could reach to the storage life of 2–4 weeks. For the packaging of fruit, perforated plastic bags or box liners are utilized (Kader 2009). Also polyethylene bags use with an ethylene absorbent preferably permanganate silica gel was suggested for extension of the storage period by 10–12 days (Banik et al. 1988).

10.1.3 Botanical Description

Sapota is one of the well-known dessert fruits, commonly known as chikoo or sapodilla. This tropical plant belongs to the family Sapotaceae (Table 10.1), including 800 species of evergreen trees and shrubs of around 65 genera. Previously sapota was named *Achras zapota* Linn and now its nomenclature has been changed from to *Manilkara achras* (Mill) Forsberg. Sapota is mainly cherished for its sweet, delicious fruits. But apart from its consumption as a fruit, it is also grown for other intentions such as for latex and timber.

Sapota fruit is a splendid sugar source (ranging 12–14%). A total of 73.7 g moisture, 21.49 g carbohydrates, 1.1 g fat, 0.7 g protein, 28 mg calcium, 27 mg phosphorus, 2 mg iron, and 6 mg ascorbic acid are contained in 100 g of edible part, as stated by Bose and Mitra (1990). Sapota fruit finds its use in the manufacturing of number of processed food products such as jams, jellies, squash, and osmo-dehydrated slices (Reddy 1959). Products like sapota milk shake, sweet chutney, nectar, dried sapota pieces, candies, pickle, blended sapota drinks, and preserves can also be prepared with good sensory quality (Sawant 1989). However, the major use is for table purpose, as it is extremely perishable fruit and has been regarded very poor in case of processing ability. It takes approximately 9 days to ripen at an ambient temperature and after harvesting it spoils within 13 days (Mohamed et al. 1996). At ambient temperatures, the fruit has a short shelf life and in order to delay its spoilage, lower temperature storage should be avoided as these are highly sensitive to lower temperatures (Bhatane 2012).

There are various shapes in which sapota fruits can be found: round, oval, conical, ellipsoidal or oblate in shape, nearly oval, round, oblate, conical, or ellipsoidal. Rigidness, gumminess, astringency, and smooth skin along with sandy brown scurf

Table 10.1 Nomenclature of *Manilkara zapota*

Kingdom	Plantae (plants)
Subkingdom	Tracheobionta (vascular plants)
Super division	Spermatophyta (seed plants)
Division	Magnoliophyta (flowering plants)
Class	Magnoliopsida (dicotyledonae)
Subclass	Dilleniidae
Order	Ebenales
Family	Sapotaceae
Genus	*Manilkara* Adans. (manilkara)

are the characteristics of unripe fruit (Karle and Dhawale 2019). When ripe, the fruit is 2–4 in. in diameter with a brown skin. The Flesh color may vary from yellow to shades of brown could have smooth or a granular texture. The fruit when raw has a leathery and rough skin which becomes smooth after ripening. A high amount of tannin content in unripe fruit ultimately can causes mouth to pucker. The flavor of ripe fruit is refreshingly pleasant and sweet. It ranges from a pear flavors to crunchy sugar (Milind and Preeti 2015).

The sapota fruits are freshly eaten in Singapore, whereas the fruit pulp finds its way to be incorporated into various food products such as ice creams, sherbets, and milkshakes. The plant is evergreen, glabrous tree with a milky juice. The prime concentrates in the peel portion of sapota are mainly the phenolic compounds including tannins, flavonoids, flavanols (catechin and epicatechin), hydroxybenzoic acids (*p*-hydroxybenzoic, gallic, and ellagic), phenolic acids, 5-caffeoyl quinic acid, flavonols (quercetin), hydroxycinnamic acids (ferulic, chlorogenic, and transcinnamic), and lycopene, kaempferol conjugates. It has been known that the extraction conditions can be optimized for the more effective recovery of the bioactive compounds (Karle and Dhawale 2019). Sapota is an excellent source of sugars (12–18%), dietary fiber (2.6%), ascorbic acid (6.0 mg/100 g), phenolic compounds (15.35 mg GAE/100 g), and minerals such as calcium (28 mg/100 g), iron (2.0 mg/100 g), phosphorous (27 mg/100 g), copper (0.086 mg/100 g), and potassium (193 mg/100 g).

Health values of sapota fruits are not restricted toward the edible portion of the fruit but nonedible part of the fruit also contribute for the beneficial effect based on the biological principles involved in it. Although the fruit peels of sapota fruits are discarded but it contains a variety of medicinally important phytochemicals. The peel of sapota is rich in antioxidant components, which may be possibly due to the presence of many bioactive phenolic compounds, that ultimately contributes to health benefits. Therefore, nowadays the researchers are quite interested in isolating these phenolic compounds and flavonoids for their incorporation for development of functional foods or nutraceutical (Karle and Dhawale 2019).

10.2 Antioxidant Properties

In the last few decades, the developing as well as industrialized countries have extended epidemic proportions of long-lasting deteriorative diseases such as cardiovascular diseases, diabetes mellitus, and metabolic syndrome. These diseases have personal implications such as reduced work capacity and high mortality, along with major matters of concern: the higher cost of public health system as well as the burden of socioeconomic status. Generally, the low-cost medicinal plant sources with countless possible effects for treatment as well as prevention of these diseases produce the readily available medications which turn out to be highly expensive and do have a number of side effects. In order to tackle this, there has been increasing research focusing on attaining newer nonallopathic alternatives with minimum risk factors. In order to investigate the influence of various diseases on plants, numerous studies have been conducted till date (Jana et al. 2012). Millions of patients are spotted with cancer every year, and the disease has high mortality rate throughout the world. Cancer prevention is one of the accepted roles of phytochemicals. It has been proved in the clinical studies that plant-derived dietary substances are considered as appropriate in the treatment of certain types of cancers because of their wide chemical variety. Suppression of cancer development takes place by blocking the action of carcinogens by phytochemicals (Norat et al. 2014).

Since ages, medicinal plants are known to have valuable anticancerous agents (Ahmad et al. 2017) that have been examined in order to find out the effective anticarcinogenic agent. It has been found out that the presence of antioxidants is related to the anticancer activity (Gupta et al. 2016). Likewise, Sapota is the fruit crop which is not chiefly grown for its medicinal properties. The plant is known with different names in different areas around the world, e.g., called as “mamay” in native Central America, Mexico, and in many parts of the world, where the plant is primarily grown for its nutrients. Antioxidants comprise of the substances or compounds that constrain the production of reactive oxygen species or interject the spreading of the free radical. There are various antioxidants present in the nature. Generally, antioxidants can be divided into two major categories such as synthetic and natural. Ascorbic acid, tocopherol, and other natural antioxidants have already been utilized into various types of products. There are various synthetic antioxidants available such as butylated hydroxyl anisole, butylated hydroxyl toluene, ethoxyquin, and propyl gallate. Plants normally produce phenolic and flavonoid compounds, which in turn being powerful antioxidants that protect them from sun (Pinnell 2003). The “phenolic compounds” comprise of approximately 8000 natural compounds: each one of these has similar structural feature known as phenol. The main group of phenolics known for human-related use is flavonoids, higher molecular weight polyphenols, and phenolic acids (Svobodova et al. 2003). Naturally occurring phenolic acids are composed of two types of frameworks of carbon: hydroxybenzoic acid and hydroxycinnamic acid structures as present in gallic and caffeic acid, respectively. Whereas the flavonoids include derivatives with benzo-γ-pyrone structure contained in a large group of lower molecular weight polyphenolic compounds. The common name for the high molecular weight polyphenols is the tannins which could be further split to hydrolysable tannins and condensed tannins. Hydrolysable tannins include the polymers of gallic or ellagic acids whereas the condensed tannins contain polymers of catechin or epicatechins (Pientaweeratch 2014).

Antioxidants functions by either inhibiting or suppressing the process of oxidation that occurs in the existence of the reactive oxygen species such as atmospheric oxygen (Cai et al. 2004). Free radicals are known to cause more than 100 diseases in humans which range from mild effects like skin ageing to severe disease like cancer. These free radicals are produced by human metabolism in response to self-defense in order to prevent further adverse effects. The formation of free radicals hastens by the environmental pressures which further increases continuously due to the present ecosystem of the world. Therefore, more and more radical scavengers or

Table 10.2 Different phytochemicals present in sapota plant

Phytoconstituents	Plant part	References
Erythrodiol, fixed oils (unsaturated and saturated), hydrocarbons (*n*-hexane, *n*-triacontane, *n*-octacosane), sterols (β-sterol, stigmasterol)	Leaf	Rashid et al. (2014) and Fayek et al. (2012)
Polyphenol oxidase, minerals (copper, zinc, calcium, potassium, Iron, β-carotene	Fruit	Milind and Preeti (2015)
Sapotinine, sapotin	Whole plant	Saradha et al. (2014)
Phenolic compounds (D-quercitol, methyl chlorogenate, dihydromyricetin, quercetin, myricitrin, myricetin-3-*O*-a-L-rhamnoside, (+)catechin, (−)epicatechin, gallic acid, D-quercitol and saccharose	Leaf, fruit, seed	Mathew and Lakshminarayana (1969)
Amino acids (arginine, lysine, aspartic acid, glutamic acid, glycine, proline, serine, threonine, valine, methionine, cysteine, tyrosine, proline, alanine, phenylalanine), carbohydrates (galactose, sucrose, fructose, glucose, lactose), ascorbic acid	Fruit, leaf	Ahmed et al. (1982)
Saponin	Stem, bark	Awasare et al. (2012)

antioxidants are needed for the prevention of this (Kanlayavattanakul and Lourith 2011a).

Nowadays, due to the increasing evidences about the role of phytochemicals in the prevention of chronic diseases like cancer, antioxidants in fruits and vegetables have acquired a large amount of attention. Phytochemicals are effective against the free radicals, which are believed to be associated with damaging of DNA, cell membranes, proteins, etc., thus give rise to chronic diseases that are associated with aging. Among these compounds, phenolics have been found to provide antioxidant capacity (AOC). There are additional phytochemical compounds including carotenoids which are known for prevention of several chronic diseases. Moreover, vitamins such as C and E are related to their antioxidant capacity. There are numerous fruits which have already been symbolized for their antioxidant properties and have been utilized in the food products for their health improvement factors. However, still there are many fruits which have potential for antioxidant properties and Sapota is one such fruit. It is consumed mostly as a dessert. The major antioxidant activity of sapota is not credited to L-ascorbic acid, a component which is accountable for antioxidant activity in many of the fruits (Leong and Shui 2002). However, it contributes some of it. It implies that major portion of the antioxidant activity is covered by the polyphenolic compounds (Shui et al. 2004). Different parts of the plant are known for different compounds responsible for the antioxidant actions (Table 10.2).

10.2.1 Fruit

It has already been reported in the literature that the sapota fruits have a very high antioxidant activity (404.75 μm Trolox equivalent/100 g) (Moo-Huchin et al. 2017). It has been investigated that sapota fruits showed antioxidant properties due to their hydrophilic extracts than the lipophilic portion and *p*-hydroxybenzoic acid was recognized as the chief phenolic compound, with the total phenolic content being 28.5 mg GAE/100 g fw. The total carotenoid content was reported to be 1127.9 μg β-carotene/100 g fw where β-carotene was turned out to be the main contributor, along with lutein and violaxanthin. δ-tocopherol was found to be 360.0 μg/100 g fw in concentration. So with the findings of this study, it could be interpreted that sapota fruit is a suitable source of carotenoids, so its inclusion in the diet could be recommended (Yahia et al. 2011).

A stronger nitric oxide scavenging action as well as constraining effects against the propagation of tumor cell has been explored in the sapota fruit as compared to other fruits like apple, grape, pomegranate, and dragon fruit (Jayakumar and Kanthimathi 2011). The presence of anticancer and antiradical compounds like quercetin, gallic acid, and chlorogenic acid has been reported in the sapota. As examined by Ma and co-workers, sapota extracts contain 4-*O*-galloylchlorogenic acid and 4-*O*-galloylchlorogenate (Ma et al. 2003). The antioxidant activity of sapota was investigated using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) scavenging assay. It was shown that it induces cytotoxicity in the SW-480 and HCT-116 human colon cell lines. It was also indicated that the peel along with the pulp contains the compound 5-caffeoyl-quinic acid (Pontes et al. 2002). Also, a higher amount of tannin content was reported to be found in the unripe sapota fruit, which is known to possess a high antioxidant activity. So, the tannin content decreases with the ripening of fruit naturally (De Brito and Narain 2002). The variations of total phenolic content and total antioxidant capacity (TAC) during the storage time in sapota were examined. Gradually, as the fruit turns from unripe to overripe, a significant decrease was found in levels of both TPC and TAC. It has been recommended that the best time for the consumption of sapota fruits at a flavorful stage having good amounts of antioxidants is when L-Ascorbic acid equivalent antioxidant capacity (AEAC) values range from 600 to 1200 mg in 100 g fresh sample. A consistency was seen in changes of antioxidant peaks with the changes of peaks during storage (Shui et al. 2004). The development of dark pigments is associated with the ascorbic acid degradation, caused by number of agents such as heat, light, catalysts, alkalinity, and humidity. Carotenoids are the compounds that are vital for the development of fruit, are highly stable and thus remain intact, even when senescence is at well advanced stage. Phenolic content of unripe fruits is found to be higher than that in ripe ones.

The extracts of sapota fruit were examined for the presence of bioactive components and thus for its ultimate application in cosmetic industry. So DPPH radical scavenging activity, oxygen radical absorbance capacity, and β-carotene bleaching activity assay methods were used for in vitro analysis of antioxidant activity. The determination included the presence of total flavonoid, total tannin, and total phenolic content in the extracts. A good correlation was seen between the antioxidant activity (DPPH) with the flavonoid and phenolic content.

An investigation by Shui and co-workers (2004) explained how the total antioxidant capacity and the total phenolic content in the various sapota king fruit batches followed a generalized trend in which both had shown a decrease with the storage time and with the progression of ripening naturally. When there is an uncertainty with the condition of cultivation as well as the stages at harvest, the variation in the total antioxidant activity could be seen naturally. A similar trend is observed in case of tannin content during ripening. A rapid fall was seen in the levels of TAC and TPC within 1–2 days after the commencement of ripening of fruits. The presence of polyphenolic components as well high tannin content was seen responsible for astringency of the fruit. The antioxidant capacity turns out to be high in case of unripe fruits, but the fruit is sappy at that stage as the flesh is tough and latex content is more (Shui et al. 2004).

10.2.2 Juices

Kulkarni et al. (2006) has reported the development of sapota juice and was analyzed for its chemical composition. It was revealed that it is rich source of sugars, protein, phenolics, ascorbic acid, carotenoids and minerals like copper, iron, zinc, potassium, and calcium. Apart from this, it exhibited antioxidant activity against DPPH free radicals and superoxide radicals. It can be utilized as a health promoting beverage due to its multifunctional properties. It was observed that the free-radical scavenging activity of juice was due to the availability of carotenoids, phenolics, and ascorbic acid. The nutraceutical value of sapota juice is directly linked to the presence of phenolics. Carotenoids play an important role in human health due to its role in Vitamin A synthesis, whereas these also contribute to some of radical scavenging activity. The ascorbic acid showed antioxidant activity depending upon the chemical environment where it is present (Kulkarni et al. 2006).

10.2.3 Seed

Sapota seed is known to find many uses in variety of ways. The main are the seed paste of sapota which is used to relieve pain as well as inflammation in case of stings and bites, and other is the preparation of sapota seed oil. The seed oil contained many fatty acids including oleic, stearic, palmate, and linoleic. Many researchers have been undertaken to know about the properties of seeds of sapota fruit. As examined by Chaianuchittrakul and co-workers, seed extracts showed low antioxidant levels among other extracts. The results implied that sapota seed extract might have significantly lower in number of active components than that of pulp extract and presented low antioxidant activity. Other investigation included the preparation of extracts by different methods and detection of presence of bioactive compounds. The level of TPC was found to be 4.00 ± 0.01 mg/g for the extract prepared by ethanol, 2.54 ± 0.02 mg/g for ethyl acetate extract, 2.26 ± 0.02 mg/g for acetone extract, and 1.21 ± 0.01 mg/g for aqueous extract of Gallic acid equivalent per 100 mg. Similarly, the levels of total flavonoid content were found to be 3.98 ± 0.01, 2.19 ± 0.01, 1.01 ± 0.02, and 0.74 ± 0.01 mg/g (of Quercetin equivalent per 100 mg) for ethanolic, acetone, ethyl acetate, and aqueous extracts, respectively.

The use of DPPH radical scavenging as a method of evaluation of antioxidant activity is widely used in case of plant and food extracts. This radical scavenging activity is known to be dependent on the dose and the nature of phenolics involved which contribute to the electron transfer ability.

Here the DPPH radical scavenging activity was found to be 51.08% at 300 μg/mL, 50.28% at 400 μg/mL, 51.99% at 500 μg/mL, and 50.46% at 500 μg/mL for ethanol, acetone, ethyl acetate, and aqueous extracts, respectively. So, it turns out that the extracts derived using ethanol exhibit significant amount of antioxidant activity in sapota seeds. So, these seeds find many applications as aperients, diuretic tonic, and febrifuge. It has a capacity of iron chelation and have reducing power.

The obtained results presented this conclusion that the sapota seed extract contains large amounts of phenolic and flavonoid constituents, due to which it shows higher antioxidant activity, and thus have medicinal properties (Shanmugapriya et al. 2011).

In another study, Sapodilla seed coat was obtained from the methods such as using EtOAc, n-hexane, and aqueous fractions. It turns out that EtOAc was the most effective method and there was a positive correlation between total phenolic content and DPPH. Moreover, the fractions showed the presence of quercetin, chlorogenic acid, and gallic acid. Quercetin presented a positive correlation with the total phenolic content. Hence, it was stated that the sapodilla seed coat was found to be the multifunctional ingredient which shows promising applications in the cosmetic industry (Kanlayavattanakul and Lourith 2011b).

10.2.4 Peels

A review by Karle and Dhawale describes about pharmacological assessment and phytochemicals of *Manilkara zapota* (L.) Royen fruit peel (MZFP) and a juice byproduct which is generally considered as wastage. It turns out the sapota peel comprises of about 20% of the fruit. The survey of literature suggested that the peel portion of the fruit is concentrated with the phenolic compounds including tannins, flavonoids, flavonols (catechin and epicatechin), conjugates of 5-caffeoyl quinic acid, phenolic acids, hydroxybenzoic acids (*p*-hydroxybenzoic, gallic, and ellagic), hydroxycinnamic acids (ferulic, chlorogenic, and transcinnamic), lycopene, and kaempferol. Generally, it has been recognized that by the optimization of the conditions for extraction, the recovery of the bioactive components from the sapota peel is easy. Primary type of evaluation in this area is mainly undertaken by in vitro methods. So, the clinical trials are required for accurate validation of the health benefits (Karle and Dhawale 2019).

10.2.5 Wastes (Leaves)

Sapota plant leaves are considered as wastage, but the leaves have some interesting properties which could be utilized in many ways. There have been many researches on this part of the plant. The antinociceptive properties of sapota plant have been described by two methods, that is, Central antinociception using radiant heat tail-flick methods and peripheral antinociception by writhing induced by acetic acid. The results indicated the use of plant part in ethnomedicine in the case of pain and diarrheal disease. It has been reported that the flavonoids play important role in the antinociceptive activity by prostaglandin targeting (Jain et al. 2010). The screening of sapota leaves extract, prepared using ethanol, exhibited the occurrence of tannin, flavonoids, phenolic constituents, and flavonoid, which in turn were responsible for the peripheral antinociceptive activity. Okwu (2005) has also presented similar observation about the role of saponins, phenolic constituents, and flavonoid in killing the pain. So, it could be assumed that the central antinociceptive activity may be caused by phenolic components (Aslam and Najam 2013). Also, the presence of saponins, flavonoid, and tannin in the plant are observed to be responsible for the antidiarrheal activities of crude ethanolic extracts (Ganguly et al. 2016).

In another study, the extracts of the sapota leaves, obtained by the sequence of extraction using solvents with different polarity, were assessed by four in vitro methods: superoxide, DPPH, reducing capacity assessment assay, and hydroxyl radical scavenging activity. It turns out that the best antioxidant activity was exhibited by the extract prepared by acetone (Chanda and Nagani 2010).

In a similar study by Fayek and co-workers (2012), it was shown that the biological activities of aqueous and alcoholic extracts of sapota leaves could be credited to the phenolic constituents, that is, Caffeic acid, apigenin-7-*O*-α-L-rhamnoside and myricetin-3-*O*-α-L-rhamnoside (Fayek et al. 2012).

10.2.6 Antioxidant Properties of Products Prepared from Sapota

Generally, the antioxidant compounds are innately low in meat and its products. So, because of the presence of moisture in addition to unsaturated fatty acids results in lipid peroxidation as well as spoilage due to microorganisms (Chatli et al. 2015). The occurrence of lipid peroxidation thus damages the organoleptic properties (due to the off-flavor, off-odors, change in appearances, and color) as well as the nutritive value. So here the study was conducted in order to examine the effectiveness of sapota powder as natural preservatives along with efficient application in field of food technology by incorporating powder at different levels (2%, 4%, 6%) by replacement of lean meat. It was found that the pork patties with 4% incorporation were ideal based on the sensory attributes. Thus, it was selected for studies during storage for the assessment of both antimicrobial and antioxidant activity both in case of aerobic environment and modified atmospheric packaging (MAP) for 42 days at 4 ± 1 °C. A gradual rise was observed in the indicators of parameters of lipid oxidation, that is, free fatty acids, peroxide value, and thiobarbituric acid reaction substances. Whereas the values in case of treated product were lower than the control (Kumar et al. 2018).

Panda and co-workers examined the formulation of wine with an alcohol concentration of 8.23%, from sapota fruit pulp which would be rich in antioxidants. Fermentation was undertaken with wine yeast known as *Saccharomyces cerevisiae* in order to keep the functional properties, nutritional and antioxidant activities preserved. The DPPH activity of wine was observed to be 46% at a dose of 250 μg/mL. The scavenging of free radicals (hydroxyl radicals ($^{\bullet}OH$) or superoxide anion radicals ($O^{\bullet-}$) was credited to the presence of polyphenols. The total phenolic content was found to be 0.21 g/100 mL for both must and wine. The stability of polyphenols was attributed to the lower pH of the wine because polyphenols tends to autooxidize at high pH. Also, the presence of ascorbic acid was observed both in must (2.86 mg/100 mL) and in wine (1.78 mg/100 mL) (Panda et al. 2014).

Phenolic compounds have a direct contribution to the antioxidant activity, as these are known as influential antioxidants which act as a terminator for free radical. These compounds scavenge the free radical because of the presence of hydroxyl group, so these are the very important component in plants. High antioxidant activity extracts possess higher number of phenolic constituents. The plants that contain phenol groups do have antimutagenic, antioxidant, and anticancer properties.

As explained in the above sections, there has been a lot of research in this area. According to recently developed method, it was utilized in order to identify and characterize the antioxidants present in a sapota fruit extract. Here, the observations included the monitoring of free radical active compounds by looking for the differences in the peak intensities in between the products of reaction and the reactants itself using a mass detector (MS). The use of a mass detector (MS) along with HPLC will make us able to monitor the active constituents as well as help to recognize their chemical structures in a biological system. A combination of MS to HPLC makes an excellent tool for the monitoring of free radical components and for the detection of chemical information of biological components.

10.3 Health Benefits

Sapota is a medicinal plant with many recognized pharmacological uses (Table 10.3). Almost every part of the plant (edible and nonedible) has some sort of health advantages on the basis of the biological principles that are involved in it. The parts of plant such as fruit peels, leaves are considered as a by-product and are discarded, but these do contain important phytochemicals possessing health benefits. For example, peel portion of the fruit contains phenolic components, which thus make the peel portion have high antioxidant activity and thus good for health. So, overall the fruit contains various flavonoid and phenolic constituents and thus many studies have been undertaken in order to investigate the health effects of the various parts of the sapota fruit (Karle and Dhawale 2019).The properties of sapota are affected by the method of extraction of the plant part used. The fruit is rich in certain nutrients such as beauty enhancement vitamins (E, A and C), proves its potential use

Table 10.3 Health uses and properties of different parts of sapota plant

Part of plant	Properties	Health benefits	References
Fruits	Contains polyphenols, carotenoids, sterols, saponins, terpenes, vitamins	Decoction is used to treat diarrhea, infusion is used to treat pulmonary complaints	McCarty (2004) and Kulkarni et al. (2006)
Leaves	Contains lupeol acetate, oleanolic acid, apigenin-7-*O*-α-L-rhamnoside, myricetin-3-*O*-α-L-rhamnoside and caffeic acid	Treat cough, cold and diarrhea. Antimicrobial, analgesic, antihyperglycemic and hypocholesterolemic, antioxidant, liver cancer	Shazly et al. (2012), Kaneria and Chanda (2012), Kaneria et al. (2009) and Ganguly et al. (2013)
Bark	Antibiotic, astringent, febrifuge Anti-inflammatory	Used as tonic and decoction is given in diarrhea, paludism and dysentery, pain, gastrointestinal disorder, anticancer	Hossain et al. (2012)
Seeds	Aperients, diuretic, tonic, febrifuge	Expel bladder and kidney stones, paste is used over the stings and bites from venomous animals	Kulkarni et al. (2006)
Juice	Nutraceutical, rich source of polyphenols	Antidiabetic, prevent dyslipidemia, and obesity	Barbalho et al. (2015)
Latex	–	Crude filling for tooth cavities	Kulkarni et al. (2006)
Peel	Contains polyphenols and flavonoids	Antimutagenic, anticarcinogenic, antioxidant, reduce cardiovascular complications, antidiabetic, anti-inflammatory, antiallergic, and antiplatelet agents	Karle and Dhawale (2019)
Pulp	Contains gallic acid, chlorogenic acid, and quercetin	High antioxidant activity	Ma et al. (2003)

as an herbal remedy in the cosmetic and skin care products. The three vitamins have a moisturizing effect on the skin. Vitamin E and C are known as natural antioxidants and used in antiaging products to reduce wrinkles and fine lines. The part of plant is used for controlling variety of health problems such as diarrhea, inflammation, and pain. Hair uses include moisturizing the scalp, treating the fungal growth, soften the hair, and treatment of hair fall (Chaianuchittrakul et al. 2016). Seed oil is utilized in case of management of curly hair as it softens the hair and is also used to treat hair fall problems. Moreover, polyphenols and flavonoids present are helpful in reduction of body weakness (Milind and Preeti 2015).

The young sapota fruits do contain high amount of tannins which are useful to treat diarrhea, bark of sapota plant is utilized in the formulation of tea which thus is used in the treatment of fever. The latex portion is used as fillers for tooth cavities, old leaves are utilized for tea preparation which thus helps in treating colds, cough, and diarrhea while the crushed seed portion is known to be sedative, soforic, diuretic, and thus utilized for kidney stones' treatment (Morton 1987).

A number of studies focus on the health effects of the different parts of sapota plant. A study was undertaken to analyze the influences of leaf in addition to pulp portion of sapota plant on the metabolic profiles of Wistar rats. In the study, male rats were given sapota fruit juice and leaf juice and the effect was seen by analyzing the body profiles of the rats. The results have shown that there was a reduction in the levels of insulin, glycemia, leptin, triglycerides, and cholesterol. So, it was concluded that the consumption of sapota fruit might help in preventing diabetes, obesity, dyslipidemia, and other complications (Barbalho et al. 2015).

Saponins and triterpenoids are components of sapota plant which find their use in the folk medicine which is possibly due to its anti-inflammatory, antimicrobial, analgesic, spermicidal, and antioxidant activities (Banerji et al. 1979). Mainly, flavonoids, polyphenols, dihydromyricetin, epicatechin, gallocatechin, quercetin, myricitrin, catechin, and gallic acid are the components that have been quarantined from fruits. The diseases like dysentery, diarrhea, and pulmonary diseases are treated using the decoction of flowers. It has been investigated in a previous study that the phenolic antioxidants such as methyl 4-*O*-galloylchlorogenate and 4-*O*-galloylchlorogenic acid that can be derived from Sapota fruits can induce cytotoxicity in colon cancer cells (Srivastava et al. 2014).

Since centuries, natural products have found their way in discovery of drugs and in this matter, anticancer agents are particularly important. In such a study, aqueous leaf extracts of *Pouteria sapota* (*P. sapota*) were investigated for its cytotoxic activity. The preliminary screening included the examination of antioxidant activity of the leaf extract using DPPH radical scavenging, reducing power, and H_2O_2 scavenging activity. The advanced analysis involved the screening of in vitro breast cancer cell lines (MCF-7) for cytotoxic activity. The results revealed that the extracts were rich in antioxidant activity and phytochemicals and have shown a considerable anticancerous activity against MCF-7. Therefore, it was concluded that sapota extracts have strong cytotoxic activity and can be utilized for treatment of cancer issues (Prabhu et al. 2018).

Srivastava et al. stated that the methanolic extract of sapota fruit is associated with dose-dependent cytotoxicity in cancer cell lines. The analysis of cell cycle advocated for activating the apoptosis, without arresting cell cycle progression. It has been established by Annexin V-propidium iodide double-staining that the fruit extracts potentially generate apoptosis instead of necrosis in cancer cells (Srivastava et al. 2014). Sapota fruit has always been reflected as a healthy fruit which could be associated with alleviation of micronutrient malnutrition. Various studies have highlighted the nutrient content of sapota which comprises of proteins, sugars, protein, acids, phenolic compounds (catechins, chlorogenic acid, gallic acid, leucodelphinidin, leucocyanidin, and leucopelargonidin), carotenoids, minerals

(Cu, K, and Fe), and vitamins (A, C, folate, and pantothenic acid). Recently, it was reported that a methanolic extract of sapota fruit inhibits tumor growth (Srivastava et al. 2014).

However, still pharmacological evidence on antiliver cancer properties of *Manilkara zapota* leaf extract does not exist in literature. It has been found that leaf water extract of *Manilkara zapota* exhibited cytotoxic activity against human hepatocellular carcinoma (HepG2) cell line. Consequently, it could be derived that this leaf extract is promising to be formulated as a complementary medicine for treating liver cancer. The apoptosis-inducing activity of leaf water extract on HepG2 cells was analyzed in order to obtain information regarding viability of cells. As per the published guidelines, any extract employing potential cytotoxic activities should be having an IC50 less than 100 μg/mL. Treatment with *Manilkarazapota* leaf water extract at high concentrations (12.5–200 μg/mL) for 24 h caused noticeable reduction in the cell viability as compared to the untreated cells (control) ($P < 0.05$) (Tan et al. 2018).

10.4 Conclusion

The chapter concludes that various botanical parts of the sapota such as seed, whole fruit, juice, stem, peel, latex, and leaves are powerhouse of different polyphenols and bioactive compounds and thus provides great benefits to human health. The presence of bioactive components in the various fraction of sapota exerts various health promoting activities antimutagenic, antioxidant, and anticancer properties. Despite of rich source of bioactive components in various parts, processed products of sapota are not available in the market, hence, further research is required to explore the potentiality and applications of this fruit in processed food products to study the fate of the bioactive compounds during processing. Therefore, Sapota is a fruit full of potential for its utilization in isolation of polyphenols for its antioxidant activity.

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Sea Bucknorn

11

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Abstract

Hippophae rhamnoides (sea buckthorn) is a well-known plant for its nutritional and health promoting properties. The bioactive compounds like phenolic acids, flavonoids, terpenoids, vitamins, amino acids, and minerals present in the sea buckthorn and its derived product are responsible for its antioxidant and pharmacological values. Recently, the researchers have gained interest in this plant due to the various antioxidant compounds present in it which are responsible for the different chronic and degenerative diseases. Sea buckthorn claimed the health benefits including antimicrobial, anticancerous, anti-inflammatory, anti-stress, and other related effects. Having high nutritional value and valuable source of natural antioxidants, sea buckthorn can be used as a nutraceutical source as well as functional foods. This chapter gives insight into the history, production, phytochemical composition, and antioxidant properties of different edible parts of sea buckthorn. Along with it this chapter also summarizes the mechanism of antioxidant action and other biological functions of sea buckthorn. The health benefits with systematic scientific reports are also highlighted.

Keywords

Sea buckthorn · Antioxidants · Phenolic acids · Flavonoids · Health benefits

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11.1 Introduction

Botanical name: *Hippophae rhamnoides*, **Common name:** Sea buckthorn

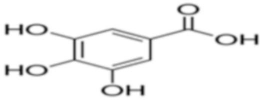
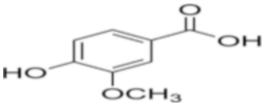
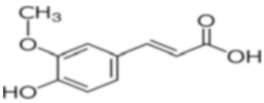
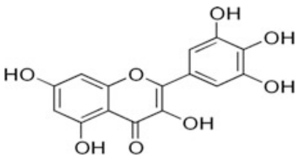
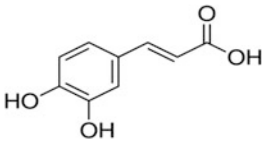
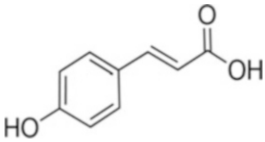
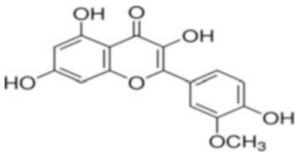
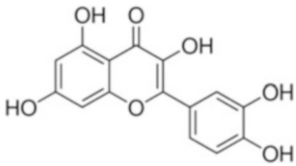
Fruits have been found to be the first food items used for human diet since a very long time. Fruits are utilized in all forms whether fresh or processed by human beings as they are rich in a variety of nutrients like minerals, vitamins, phytochemicals, etc. There are many underutilized wild fruits present in the different regions of developing countries across the world. Natural commodities are important for rural commodities as they give many useful materials. The underutilized wild fruit trees that are not utilized in any way can be consumed as fruits or used as fuel or for building materials. Hippocrates, who is known as "the father of modern medicine," quoted "let food be your medicine and medicine be your food." New advances in this field may promote the usage of both therapeutic and nutritious food products.

Sea buckthorn (*Hippophae rhamnoides* (L.); SBT) belongs to the family Elaeagnaceae and is a small tree which is naturally present all over Eurasia, i.e., Central Asia in the East and north and Baltic Sea in the West (Xing et al. 2002a, b). This is a hardy plant, immune to drought and cold. It also helps to restore land and conserve farmland because of its overall healthy vegetative reproduction as well as strong and complicated root network with nitrogen-fixing nodules (Rongsen 1992). Among the various parts of sea buckthorn, its berries are specially used in Chinese, Mongolian, and Tibetan traditional medicines and possess various therapeutic activities (Wei et al. 2019).

Sea buckthorn (SBT) chemical analysis showed that it contains various bioactive compounds like phytosterols, fatty acids, flavonoids, carotenoids, sugars, amino acids, vitamins, and minerals which provide important pharmacological effects (Guliyev et al. 2004; Stobdan et al. 2013). Sea buckthorn berries are derived from a variety of bioactive compounds (Table 11.1) that include quercetin, isorhamnetin, cirsiumaldehyde, 5-hydroxymethyl-2-furancarboxaldehyde, hippophae cerebroside, oleanolic acid, dulcioic acid, palmitic acid, ursolic acid, 19-α-hydroxyursolic acid, octacosanoic acid, and 1-O-hexadecanolenin (Zheng et al. 2009; Suryakumar and Gupta 2011). Seeds and pulp of fruit are rich source of oil containing 8–20% in mature seeds and 20–25% in dried fruit pulp (flesh and peel), and fruit residue after juice extraction contains 15–20% oil content (Zeb 2004; Kumar et al. 2011; Christaki 2012). The unsaturated fatty acid, phytosterol, and vitamins A and E are the rich source of lipophilic constituents of its oil which primarily lead to healthy human's cardiovascular system (Kumar et al. 2011; Olas 2016, 2017). Sea buckthorn fruits are also gaining attention in functional food production because of its high nutritional and therapeutic value (Ding et al. 2016).

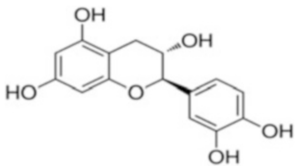
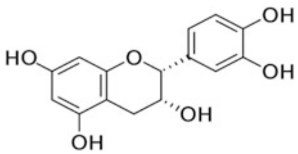
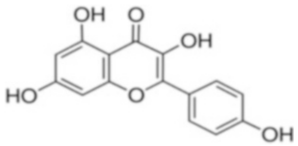
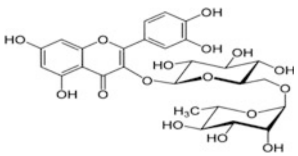
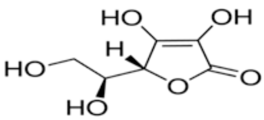
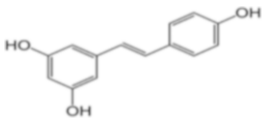
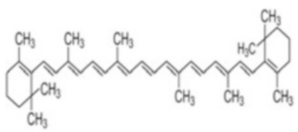
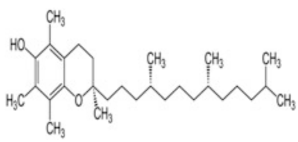
Different sea buckthorn berry products like sea buckthorn oil, juice, drink, etc. are gaining interest in various countries like India, United States, Canada, China, and some European countries due to its nourishing effects and medicinal value (Guliyev et al. 2004; Tulsawani 2010). This chapter includes detailed study of antioxidant properties and characterization of the chemical compounds that account to the antioxidant properties of different parts of sea buckthorn. The health benefits of

Table 11.1 Bioactive compounds and their structure present in different parts of sea buckthorn

S. no.	Bioactive compound	Structure	Part of plant used	References
1.	Gallic acid		Fruit	Madawala et al. (2018)
2.	Vanillic acid		Fruit	Madawala et al. (2018)
3.	Ferulic acid		Fruit	Madawala et al. (2018)
4.	Myricetin		Fruit	Madawala et al. (2018)
5.	Caffeic acid		Fruit	Madawala et al. (2018)
6.	p-Coumaric acid		Fruit, leaf, pomace	Madawala et al. (2018) and Radenkovs et al. (2018)
7.	Isorhamnetin		Fruit, leaf, pomace	Madawala et al. (2018) and Radenkovs et al. (2018)
8.	Quercetin		Fruit, leaf, pomace	Madawala et al. (2018) and Radenkovs et al. (2018)

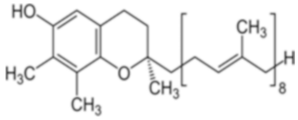
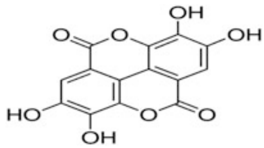
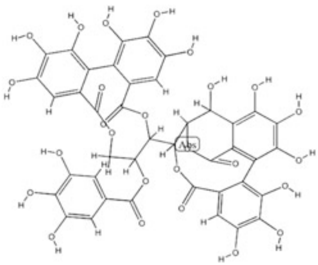
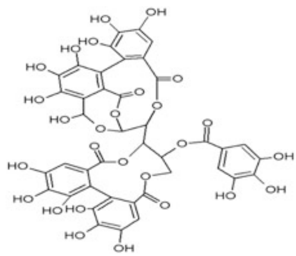
(continued)

Table 11.1 (continued)

S. no.	Bioactive compound	Structure	Part of plant used	References
9.	Catechin		Fruit, leaf, pomace	Radenkovs et al. (2018)
10.	Epicatechin		Fruit, leaf, pomace	Radenkovs et al. (2018)
11.	Kaempferol		Fruit, leaf, pomace	Radenkovs et al. (2018)
12.	Rutin		Fruit, leaves	Zu et al. (2006)
13.	L-Ascorbic acid		Fruit	Jeppson and Gao (2008)
14.	Trans-Resveratrol		Fruit	Gorbatsova et al. (2007)
15.	β-Carotene		Fruit, leaf, shoots, buds	Górnaś et al. (2016)
16.	Tocopherol		Fruit, leaf, shoots, buds	Górnaś et al. (2016)

(continued)

Table 11.1 (continued)

S. no.	Bioactive compound	Structure	Part of plant used	References
17.	Plastochromanol-8		Fruit, leaf, shoots, buds	Górnaś et al. (2016)
18.	Ellagic acid		Leaf	Cho et al. (2017)
19.	*Stachyurin*		Leaf	Ma et al. (2019)
20.	Casuarinin		Leaf	Ma et al. (2019)

sea buckthorn with related scientific studies and different metabolic pathways involved in biological activities are also highlighted.

11.1.1 History

The word *Hippophae* came from the Latin words "Hippo," which means horse, and "Phaos," which means "shine." In Greece, sea buckthorn leaves help in gaining of weight and shining coat when used as a feed especially for horses, and history has shown that it can also be used for treating various medical conditions. Different pharmacological effects are registered in classics that include Sibu Yidian from the Tang Dynasty and Jing Zhu Ben Cao from the Qing Dynasty (Suryakumar and

Gupta 2011). After the thirteenth century, when the RGyud Bzi was spread across Mongolia, SBT was also used in Mongolian traditional medicine. In Central Asia and Europe, sea buckthorn berries were used as herbal medicines and as a health food (Li and Hu 2015; Olas 2018). These people use berries for the treatment of hypertension, skin, and digestive system-related problems, whereas Indian Himalayas and Russian regions used it for gastrointestinal, rheumatism, and asthma problems (Suryakumar and Gupta 2011; Malinowska and Olas 2016; Olas 2017). Russia during the 1950s started the clinical studies in therapeutic use of SBT (Gurevich 1956). However, sea buckthorn was first accepted as a drug by China, which is formally included in 1977 by Chinese pharmacopoeia and used to treat various diseases (Kumar et al. 2011). The berry oil was utilized for treating inflammation of genital organs, erosion of uterus, gastritis, and stomach ulcers; moreover, infusion of dried berries is used for treating skin diseases by many people (Li 1999). In Germany, SBT was used since a long time, for the environmental restoration of degraded fields, especially to recover dumps of coal mines and industries as well as to prevent soil erosion (Suryakumar and Gupta 2011).

11.1.2 Production

In the early 1930s, scientists in the former Soviet Union were influenced by historical literature and started conducting research on sea buckthorn. Nowadays, several countries around the world have been studying this amazing plant. Today approximately 40 different countries are cultivating sea buckthorn. Currently, the area covered by sea buckthorn production is around 3 million hectare across the world. China, Russia, Canada, Mongolia, and Northern Europe cover almost 90% of the world's sea buckthorn. China is the leading producer across the globe with total cultivated area of over 300,000 ha whereas total area under wild sea buckthorn is 740,000 ha and total annual yield of sea buckthorn is about 8.5 million tonnes (Jianzhong et al. 2008). Mongolia harvested 1200–1600 tonnes of berries annually with total cultivated area of 6000 ha and 13,500 ha (wild collection) (Oyungerel et al. 2014; Gonchigsumlaa 2016). Moskalets et al. (2019) reported that the area under sea buckthorn cultivation in Ukraine is 60.5 ha with production of 12–15 kg fruits per plant.

In India, the Defence Research and Development Organisation (DRDO), Indian Council of Agricultural Research (ICAR), Indian Council of Medical Research (ICMR), Department of Biotechnology (DBT), and other organizations cultivated and performed researches on the sea buckthorn. The total area under sea buckthorn cultivation is around 13,000 ha with annual production of 600 tonnes approximately. Ladakh is the major site for sea buckthorn cultivation covering approx. 70% (9276 ha) of total cultivated area in the country (Stobdan and Phunchok 2017).

11.1.3 Botanical Characteristics

Sea buckthorn (*Hippophae* L.) comes under the family Elaeagnaceae and genus *Hippophae* (Sharma and Kalkal 2018). The family includes around 100 species in three genera that are mostly present in the moderate geographical latitudes of the Northern Hemisphere. Classification of sea buckthorn is indigenous to Central Asia and North-Western Europe (Řezníček and Plšek 2008). It usually grows as a shrub, but sometimes reaches the height of 5–8 m and grows as a small tree (Niesteruk et al. 2013). The hydrolapathum-shaped leaves of SBT are gray-green in color from top with smooth and shiny surface and hairy with a light brown shade from the bottom (Li and Beveridge 2003). The buds present on sea buckthorn shoots are of golden copper color with higher number in male individuals, and also silver hairs are present on young shoots (Hu 2005). The berries of sea buckthorn are dioecious and anemophilous. Flowers do not produce nectar; therefore, pollination by insects is not possible; the only possibility is wind pollination (Li and Beveridge 2003). Flowers bloom in April end and are seen until the leaves develop (Niesteruk et al. 2013). Berries are 6–9 mm in diameter, yellow to orange red in color (Fig. 11.1), and with round and oval in shape as well as soft, juicy, and rich in oils (Suryakumar and Gupta 2011). These berries grow at an altitude of 2000–3600 meters above sea level. They are highly temperature resistant with a wide range of temperature (−45 to +43 °C) and generally grow on steep slopes having sunny side or riverbanks (Dhyani et al. 2007). Sea buckthorn berries tolerate severe conditions like drought, acid soils, and high soil salinity (Khan et al. 2010). It has good root system with root hairs and is mostly found in the apical region. Most of the roots are present in the topsoil, which prevents soil erosion (Rongsen 1992).

Fig. 11.1 Sea buckthorn berries and leaves

11.2 Antioxidant Properties of Fruit, Juices, Seeds, Peels, Wastes, and Its Products

As sea buckthorn has tremendous nutritional and therapeutic benefits, it has drawn the attention of researchers and environmentalists from all over the globe. Over 190 bioactive compounds have been reported from various plant parts (Bal et al. 2011). As every part of the plant has some nutraceutical or therapeutic value, therefore, it is known to be a "multipurpose-wonder plant" or "golden bush" (Li and Schroeder 1996). The variety of bioactive compounds present in the various parts of sea buckthorn are the main reason for its antioxidant properties.

11.2.1 Fruit

Sea buckthorn berries are rich source of natural antioxidant including phenolics, flavonoids, carotenoids, organic acid, ascorbic acids, and fatty acids (Tiitinen et al. 2006). In Asia and Russia, berry extract was utilized for nutritional as well as medicinal purposes like herbal dietary supplement, cosmeceuticals, and nutraceuticals for a long time for the prevention of cardiovascular and cerebrovascular diseases (Sharma and Kalkal 2018). Sea buckthorn berries showed $29.6 \pm 1.9\%$ activity through DPPH assay and 100.6 ± 1.4 TE mg/100 mL through ORAC assay (Tian et al. 2018). Ultrasound-assisted extraction, high-pressure processing, and supercritical fluid method using different solvents were also used to evaluate antioxidant activity, and it was found that the highest antioxidant activity (approx. 30%) was observed in supercritical fluid extraction method because it contains the highest concentration of flavonoids (Radulescu et al. 2019). The four subspecies of *Hippophae rhamnoides* L. were studied for their phytochemical, antioxidant, and antiproliferative properties and found that the highest phenolic content and significant antioxidant activity were found in *Hippophae rhamnoides* L. subsp. *sinensis*, whereas *Hippophae rhamnoides* L. subsp. y*unnanensis* showed maximum cellular antioxidant and antiproliferative activities against human cancer HepG2 cells (Guo et al. 2017). The high phenolic content of sea buckthorn fruits exhibits antioxidant and antiplatelet activity in human blood plasma and platelets (Olas et al. 2016). Sea buckthorn fruit extract also showed significant antioxidant activity and cytoprotective effect against cellular oxidative stress in the embryonic fibroblast cells of mouse due to change in the regulation of cell cycle, which prevents apoptotic cell death (Lim et al. 2013).

11.2.2 Juices

Sea buckthorn berries contain approximately 60–85% juice and rich source of vitamin C, omega 3,6,9 fatty acid, and rarest omega 7. The protein content varied from 0.79 to 1.64% with 18 types of amino acids (Chen 1988). TSS of berry juice is 10.7–13.2 °Brix with maximum amount of glucose and fructose. Sea buckthorn juice is a tremendous source of antioxidants, and vitamin C is the dominant antioxidant with a concentration of 2500 mg/kg in *H. sinensis* and above 300 mg/kg in *H. rhamnoides* (Bal et al. 2011). Mendelová et al. (2016) reported that total phenolic content and total antioxidant activity range from 13.03–25.35 mgGAE/dm^{-3} DM and 45.11–108.77 mgAA/dm^{-3} DM respectively in 11 varieties of sea buckthorn juice. Alexandrakis et al. (2014) studied the effect of thermal processing and high-pressure processing on pectin methylesterase (PME) (responsible for cloud loss) and antioxidant activity of sea buckthorn juice. It was found that processing of juice at 60 °C for 1 min results in 2.5-fold reduction in antioxidant activity and 50% in PME inactivation, whereas antioxidant activity was slightly increased when 200–600 MPa pressure was applied at ambient temperature. HPLC analysis showed that flavonols are the predominating polyphenols in sea buckthorn juice with isorhamnetin-3-O-glycoside as the most dominant while phenolic acids and catechins as minor polyphenols. Flavonols due to structural properties exhibit less antioxidant activity as compared to phenolic acids and catechins. Ascorbic acid being the major antioxidant with concentration of 1.22 g/L contributes 75% approximately of total antioxidant activity of sea buckthorn juice (Rösch et al. 2003). In another study the major antioxidants present in sea buckthorn juice are vitamin E (13.3 mg/L), carotenoids (7.3 mg/L), vitamin C (1540 mg/L), and flavonoids (1182 mg/L), while isorhamnetin covers almost 50% of total flavonoids. Vitamin E is mostly present in the form of α-tocopherol (Eccleston et al. 2002).

11.2.3 Seed

Sea buckthorn seed is 2.8–4.2 mm in size, ovoid to elliptical in shape, and dark brown in color as well as known to have a variety of therapeutic compounds (Suryakumar and Gupta 2011). The yield of seed oil is 10–20% constituting mainly unsaturated fatty acid with highest percentage of linoleic acid (30–40%) and α-linolenic acid (20–30%) (Yang and Kallio 2002; Zeb 2004). The seed oil of sea buckthorn contains good antioxidant property which protect against oxidation stress from heat-oxidized lipids (Zeb and Ullah 2015). The CCl_4-induced toxicity was inhibited by sea buckthorn seed oil due to increased antioxidant-related enzymes like catalase, glutathione reductase, glutathione peroxidase, superoxide dismutase, and reduction of malondialdehyde, which showed its capability as a natural antioxidant agent (Ting et al. 2011). Fan et al. (2013) evaluate antioxidant activity of sea buckthorn seeds using copper-catalyzed lecithin liposome oxidation assay and found that 70% acetone extract showed maximum antioxidant activity. Seed extracts inhibit the formation of conjugated diene hydroperoxides (0–90%) and thiobarbituric acid reactive substance (TBARS) (0–88.6%) at a concentration of 250 μg/ml. Negi et al. (2005) reported that sea buckthorn seed methanolic extract showed highest antioxidant and antibacterial activity.

11.2.4 Pomace

The commercial production of sea buckthorn juice results in a large amount of pomace, which is known to have large quantity of valuable natural antioxidants. It has been utilized in various food products for its value addition. The antioxidant potential of three different extracts (100% methanolic, 70% methanolic, 100% aqueous) of pomace was evaluated, and 100% methanolic was a better scavenger of ABTS ($IC_{50} = 0.717 \pm 0.049$ mg/ml), DPPH ($IC_{50} = 105.62 \pm 21.35$ μg/ml), and hydroxyl radicals ($IC_{50} = 16.67 \pm 0.31$ μg/ml), and 70% methanolic extract was a better scavenger of superoxide and nitric oxide radicals with IC_{50} value of 142.15 ± 14.43 μg/ml and 61.99 ± 4.25 μg/ml, respectively (Kant et al. 2012). Varshneya et al. (2012) studied the total phenolic content and antioxidant potential of sea buckthorn pomace without seeds, and it was found that aqueous methanolic extract has lower IC_{50} value for DPPH, ABTS, superoxide, and nitric oxide free radicals, whereas methanolic extract has lower value for hydroxyl extract. Rösch et al. (2004) reported that oligomeric fraction of sea buckthorn pomace contains 75% of total antioxidant activity and 84% of total proanthocyanidins. The predominant subunit in pomace oligomeric fraction was (+)-gallocatechin which was quantified by HPLC.

11.2.5 Products Prepared from Sea Buckthorn

The demand for functional foods is increasing day by day all over the world which contain novel ingredients with high nutritional value and therapeutic effects (Siro et al. 2008). SBT products have a wide range in market, from juice, oil, jellies, and candies to cosmetics (Sharma and Kalkal 2018). Due to high antioxidant properties present in sea buckthorn fruit, the products formulated by using it are also rich source of antioxidants. Selvamuthukumaran and Khanum (2014) developed antioxidant-rich jam from sea buckthorn berry fruit and found jam contains more natural antioxidants (antioxidant activity: $69.39 \pm 0.61\%$) with good texture as compared to commercial jams available in the market. Also less microbial spoilage with 8-month storage period at room temperature was detected. Sea buckthorn oil is also used in anti-aging and anti-wrinkle cosmetics as it delays aging process by removing free radicals. Incorporation of sea buckthorn juice and its by-product in the chewing candy increases its antioxidant potential as well as antimicrobial activity (Lele et al. 2018). Nilova and Malyutenkova (2018) developed bakery products by adding sea buckthorn seed, peel, and marc powder, and antioxidant activity of bakery products increased in the following order: BP with seed-based powder $<$ BP with peel-based powder $<$ BP with marc-based powder.

11.3 Characterization of the Chemical Compound(s) Responsible for Antioxidant Properties and the Pathways Involved in the Biological Activities

Phenolic acids, flavonoids, terpenoids, fatty acids, amino acids, vitamins, and minerals are the main bioactive compounds present in the sea buckthorn. Table 11.1 represents the major bioactive compounds along with their structures. Isorhamnetin, quercetin, ursolic acid, epigallocatechin, and ascorbic acid are the most studied polyphenols in existing literature which are responsible for the antioxidant as well as various pharmacological properties of sea buckthorn. Chemical composition and antioxidant content of the berries are responsible for the total antioxidant activity. Different components present in the plant extract are responsible unequally for the antioxidant capacity. In the existing literature, different compounds present in the plant are responsible for the different mechanisms of antioxidant actions. Figure 11.2 summarizes the literature information about the mechanisms of antioxidant action of *Hippophae rhamnoides* (sea buckthorn).

Antioxidants present in sea buckthorn activate nuclear factor E2-related protein 2 (Nrf-2) transcription factor and inhibit nuclear factor kappa B (NF-kB) of redox signaling pathway which in turn activates antioxidant enzymes which are responsible for antioxidant activity and considered as one of the mechanisms of action of sea buckthorn antioxidant activity (Wang et al. 2018). Sometimes sea buckthorn antioxidants may directly react with reactive oxygen species (ROS) or reactive nitrogen species (NOS) and exhibit antioxidant activity. Sea buckthorn also inhibits

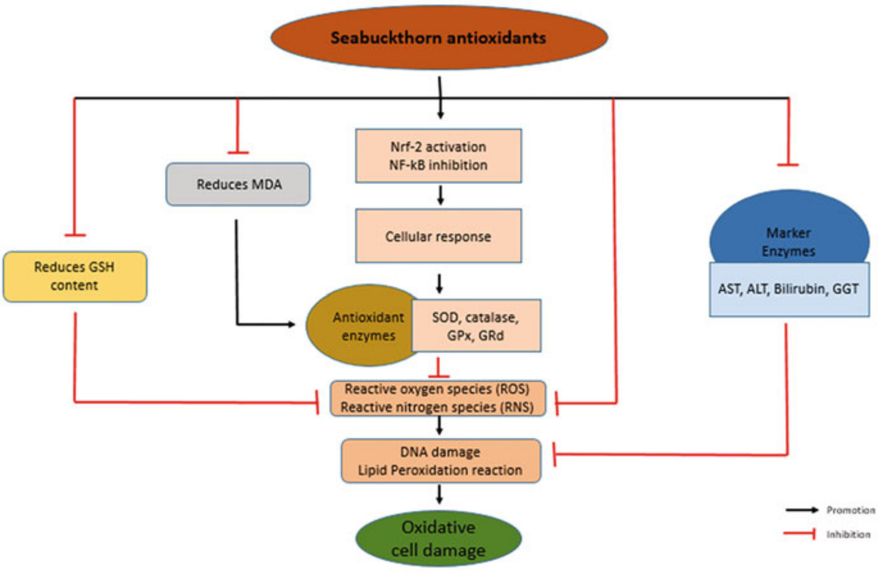


Fig. 11.2 A schematic representation of different pathways involved in antioxidant mechanism of action of sea buckthorn

oxidative cell damage by inhibiting marker enzymes and shows antioxidant activity. Inhibition of MDA also promotes the activation of antioxidant enzymes to prevent oxidative cell damage. Similarly reduction in GSH content inhibits formation of ROS/NOS to protect the cellular damage from these reactive species (Geetha et al. 2003).

Sea buckthorn also follows some other pathways to exhibit various biological functions and provides health benefits. Li et al. (2014) stated that isorhamnetin inhibits the PI3K-Akt-mTOR pathway, which is responsible for colorectal cancer, and thus acts as a potent anticancer compound. In another study on A549 lung cancer cell lines, it was observed that when cell line was treated with isorhamnetin for 24 h, it accumulated in G0/G1 phase with concomitant losses occurring in S phase, indicating continued mitosis of cells, and was unable to enter the S stage by inhibiting cyclin D1 and thus failed to activate DNA synthesis (Li et al. 2015).

Hippophae rhamnoides branches are found to contain rich source of tripernoids, which are responsible for inhibiting tumor growth. Ursolic acid and epigallocatechin are two main triterpenoids which inhibit the tumor promotion. Ursolic acid inhibits the tumor promotion by suppressing lipoxygenase, cyclooxygenase-2, matrix metalloproteinase 9, inducible NO synthetase, and tumor necrosis factor-α and apoptosis, whereas epigallocatechin inhibits the inducible NO synthetase protein in activated macrophages, thus acting as antitumor agent (Yasukawa et al. 2009). Quercetin an important flavonoid present in *Hippophae rhamnoides* fruit and leaves is a potent antiviral agent by increasing the level of interferon and binds to viral polymerases and interferes in viral nucleic acid synthesis. It also showed antidengue activity by affecting the intercellular dengue virus replication or by reduction in oxidative stress (Agarwal et al. 2016).

Sea buckthorn polysaccharide decreased the level of ALT and AST in mice and does not affect the metabolism of APAP. It also increased GSH and GSH-Px level, and expression of NO and iNOS was reduced with diminished liver injuries. The western blot study revealed the increased expression of Bcl-2/Bax, and APAP-induced JNK phosphorylation was suppressed. Furthermore, expression of Nrf-2 was also increased, which targets the HO-1 gene in APAP mice. This activation of Nrf-2/HO-1-SOD-2 signaling pathway is associated with the protective effect of sea buckthorn polysaccharide (Wang et al. 2018).

Hu et al. (2011) studied the anti-inflammatory activity by evaluating the effect of sea buckthorn fatty acids on cAMP/PKA pathway in aged rats. Imbalance in cAMP/cGMP is responsible for aging process. Fatty acids of sea buckthorn increased the level of cAMP in serum, and increased concentration of cAMP raised the PKA activity of hepatic tissue. This regulated cAMP/cGMP balance and enhanced cAMP/PKA pathway might be responsible for antioxidant and anti-inflammatory activity of sea buckthorn.

The high concentration of sea buckthorn leaf extract protects albino male rats from chromium-induced oxidative stress. Leaf extracts at high concentration (100 mg/kg and 250 mg/kg body weight) decrease the level of MDA in plasma which in turn control the level of GSH and GPx antioxidants in the intracellular matrix and reduce the oxidative stress induced by chromium. Furthermore, leaf extracts also decrease the activity of CPK, SGOT, and SGPT in chromium-treated animals and reduced hepatic damage (Geetha et al. 2003).

11.4 Health Benefits

11.4.1 Antimicrobial Activity

From thousands of years plants perform various functions like they impart flavor and conserve food and treat various health disorders. Their roles in healing are known and therefore are used over the centuries within and among human communities. There is a production of active compounds during secondary vegetal metabolism which are mainly responsible for different biological properties that are utilized all over the world for a variety of purposes, including treatment of infectious diseases (Silva and Fernandes 2010). Secondary metabolites like tannins, alkaloids, phenolics, etc. produced by plant are found to have antimicrobial activity (Guil-Guerrero et al. 2004). Antimicrobial activity is quantified by agar well diffusion assay and in most experiments by two bases, MIC (minimum inhibitory concentration) "the lowest concentration at which inoculum viability is significantly decreased (>90%)" and MBC (minimum bactericidal concentration) "the concentration where 99.9% or more of the initial inoculums is killed" (Tajkarimi et al. 2010). Chauhan et al. (2007) studied the antibacterial activity of sea buckthorn aqueous seed extract with MIC value of 750 ppm and 1000 ppm against *L. monocytogenes* and *Y. enterocolitica*. Gupta et al. (2012) also studied that seed extract of *Hippophae salicifolia* had antibacterial and antifungal activity against some strains of bacteria and fungi. Sea buckthorn aqueous and hydroalcoholic leaf extracts inhibit the growth of *B. cereus, S. aureus, E. faecalis*, and *P. aeruginosa* (Upadhyay et al. 2010). Gill et al. (2012) reported that sea buckthorn methanolic leaf extract showed maximum inhibition against *E. coli* (25 mg/ml) out of *M. luteus, E. coli*, and *A. protophormial*. The leaf extract of sea buckthorn also showed significant antidengue activity against type-2 dengue virus-infected blood-derived human macrophages with decrease in TNF-α and increased IFN-γ (Jain et al. 2008). Kumar et al. (2013) also studied the antibacterial activity of sea buckthorn leaf extract (SLE) and phenolic rich fraction (PRF) of sea buckthorn against *E. coli, S. typhi, S. aureus, S. pneumoniae*, *and S. dysenteriae*, and it was found that phenolic rich fraction was more active against all bacterial species. They also reported that higher phenolic content (319.33 ± 7.02 mgGAE/g) especially flavonoids is responsible for higher antibacterial activity of PRF. In another study, antibacterial activity of sea buckthorn methanolic leaf extract (0.5, 2, 3, 4, 5%) was evaluated against 160 microbial species isolated from skin and wound infection cases of a variety of animal species, and it was observed that 5% concentration of leaf extract showed 50% inhibition as compared to standard drugs (Verma et al. 2011). Hiporamin, a purified tannin obtained from sea buckthorn berries, was known to have antiviral activity against HIV-1, herpes simplex type 1, adenovirus type 2, influenza virus, and less antibacterial activity (Shipulina et al.

2006). Sea buckthorn berry juice was found to have good antibacterial activity against various bacterial strains (Widén et al. 2015).

11.4.2 Hepatoprotective Effect

Liver diseases are one of the leading causes of death in the world. The liver performs a vital role in metabolism, secretion, storage, and detoxification of endogenous and exogenous substances. In the liver, bio-activation of xenobiotics (e.g., drugs or toxic foods) would possibly generate reactive metabolic species to react with cellular macromolecules to cause protein dysfunction, oxidative stress, lipid peroxidation, and DNA damage (Dey et al. 2013). Liver cells are mainly damaged due to drugs, xenobiotics, metabolites, and alcohol and thus release aspartate aminotransferase (AST) and alanine aminotransferase (ALT) into the blood. Intrinsic and idiosyncratic are the main classification of mechanism of liver injury in which intrinsic injury leads to cholestasis, necrosis, and multiple lesions with minimal inflammation and can be predictable and also dependent on xenobiotic dose, whereas idiosyncratic reactions are independent of dose and directly lined with extrahepatic lesions (Sturgill and Lambert 1997; Pingili et al. 2019). Gao et al. (2003) studied that sea buckthorn extract helps in reduction of serum laminin, total bile acid, hyaluronic acid, and collagen type III and IV level in the liver which signifies that it prevents synthesis of collagen and other components of extracellular matrix. The level of ALT, AST, triglyceride, malondialdehyde (MDA), alkaline phosphatase (ALP), and cholesterol level in serum was significantly reduced in CCl_4-treated male ICR mice when sea buckthorn seed oil at a concentration of 0.26 mg/kg body was orally administrated for 8 weeks (Hsu et al. 2009). Maheshwari et al. (2011) reported that gallic acid, isorhamnetin, kaempferol, quercetin, and myricetin present in leaf extract of sea buckthorn are responsible for hepatoprotective effect against CCl_4 in the liver. Sea buckthorn berry oil also reduces the COX 2, Bcl-2, and p53 protein expression in aflatoxin B1-treated liver of chicken, thus showing hepatoprotective activity (Solcan et al. 2013). Recently polysaccharide extracted from sea buckthorn berry was found to have hepatoprotective activity against acetaminophen (APAP)-induced hepatotoxicity. Sea buckthorn polysaccharide decreased the level of ALT and AST in mice and does not affect the metabolism of APAP. It also increased GSH and GSH-Px level, and expression of NO and iNOS was reduced with diminished liver injuries. The western blot study revealed the increased expression of Bcl-2/Bax and APAP-induced JNK phosphorylation was suppressed. Furthermore, expression of Nrf-2 was also increased which targets the HO-1 gene in APAP mice. This activation of Nrf-2/HO-1-SOD-2 signaling pathway is associated with the protective effect of sea buckthorn polysaccharide (Wang et al. 2018).

11.4.3 Anti-inflammatory Activity

Inflammation is one of the main causes of atherosclerosis. It is also found in other disorders occurring in metabolic syndrome, e.g., diabetes. Diseases that occurred due to inflammation are highly responsible for morbidity and reduce workforce around the world. The use of steroidal and nonsteroidal drugs for treatment of inflammatory diseases makes various human organs highly prone to toxicity. Sea buckthorn whole fruit, pulp, leaves, and seed oil showed anti-inflammatory properties. Ganju et al. (2005) reported the anti-inflammatory activity of leaf extract of sea buckthorn by suppressing proliferation of lymphocyte in arthritis rat models. Larmo et al. (2007) studied the reduced effect of sea buckthorn on C-reactive protein (a potent inflammation marker) which may cause various cardiovascular diseases. It was also reported that leaf extract of sea buckthorn inhibits production of nitric oxide which could be due to inhibition of transcription of iNOS gene which was quite evident at translation level on probing with Moab against iNOS. The onset of the NO production cascade induced by lipopolysaccharides in macrophages required a number of steps such as the activation of nuclear factor (NF)-kh and subsequent iNOS mRNA expression (Padwad et al. 2006). Yasukawa et al. (2009) reported that anti-inflammatory activity of sea buckthorn branches' ethanolic extract is due to epigallocatechin and ursolic acid present in them. In another study, seed oil of *H. rhamnoides* and *H. salicifolia* at 4 ml/kg intraperitoneal dose showed significant effect against all inflammatory mediators, whereas *H. salicifolia* did not show any positive response against LT-induced inflammatory response. Polyunsaturated fatty acids present in both the species might be responsible for cyclooxygenase inhibition in *H. salicifolia* and amino acid metabolism in *H. rhamnoides* (Dubey et al. 2018).

11.4.4 Anticancer

Cancer is the leading cause of death across the globe as it is capable to infect any part of body (Gao et al. 2019; Rashid et al. 2019). In 2018, 18.1 million new cancer cases were found which leads to millions of deaths (WHO, cancer, who.int/news-room/fact-sheets/detail/cancer). Conventional drugs and treatments like surgery, chemotherapy, and radiation are commonly used in treatment of cancer. Due to high cost of these treatments scientific community is focusing on medicinal plants due to presence of abundance anticancerous agents in them. Sea buckthorn fruits showed anticancer effect as it decreased the carcinogen-induced skin and stomach tumorigenesis. This anticancer effect might be due to upregulation of antioxidant and phase II enzymes as well as DNA-binding activity of IRF-1, a known anti-oncogenic transcription factor which suppresses the growth and apoptosis of cancer infected cells (Padmavathi et al. 2005). Teng et al. (2006) reported that isorhamnetin isolated from sea buckthorn showed antitumor activity in human hepatocellular carcinoma cells (BEL-7402). Isorhamnetin was also found to suppress P13K-Akt-mTOR pathway in colon cancer cells, thus acting as potent anticancer agent (Li et al. 2014, 2015). *Hippophae rhamnoides* leaves' ethanolic extract exhibits antiproliferative effect on human acute myeloid leukemia cells (KG-1a, HL60, and U937) by activating S-phase checkpoint which leads to cell cycle deceleration and induction of apoptosis (Zhamanbaeva et al. 2014). The anticancer activity of *H. salicifolia* methanolic extract was also observed against Ehrlich Ascites Carcinoma cells on Swiss albino mice at a dose of 50 and 100 mg/kg body weight. It was seen that tumor weight and volume as well as viable cell count were significantly decreased, whereas life span was increased by 34% and 43% of the cells at 50 and 100 mg/kg body weight dose respectively. After sea buckthorn treatment, biochemical, hematological, and antioxidant parameters of liver tissue were also returned to normal level significantly (Chakraborty et al. 2015). Enkhtaivan et al. (2017) found that flavonol glycosides (di-glycosides and tri-glycosides) present in leaf extract of sea buckthorn were responsible for higher cytotoxic effect in human cancer cell lines. Oleanolic acid and hippocorosolate, new corosolic ester derivative isolated from sea buckthorn berries, were responsible for anticancer activity against lung (NCI-H460) and breast (MCF-7) cancer cell lines with IC50 values of ~3 μM and ~ 6 μM, respectively, whereas other ester derivative 1-(2- hydroxynaphthalen-1-yl) ethan-1-one was active only against breast cancer cells with IC50 value of ~43 μM (Ali et al. 2019).

11.4.5 Cardioprotective and Anti-antherogenic Effects

Cardiovascular diseases include the disorders in the heart and blood vessels which are responsible for approximately 23.6 million people death across the globe (Ahmad and Beg 2013). The two major risks for cardiovascular diseases are hyperlipidemia and hypercholesterolemia, and others include coronary heart disease, coronary artery disease, atherosclerosis, stroke, myocardial infarction, peripheral arterial disease, and arrhythmia (Zhao 2016). Medicinal plants including sea buckthorn are rich source of flavonoids and other bioactive compounds which help in treatment of cardiovascular diseases (Suryakumar and Gupta 2011; Singh and Chaudhuri 2018). Isorhamnetin and quercetin are the two main flavonoids present in the fruit and leaves of sea buckthorn which exhibits protective effects on myocardial ischemia and reperfusion, tumors, oxidative injury, and aging (Eccleston et al. 2002). Bao and Lou (2006) studied the sea buckthorn flavonoids' protective effect on oxidized low-density lipoprotein (ox-LDL)-induced injury in endothelial cell line. The cell death and secretion disorders were prohibited by flavonoids of sea buckthorn by preventing ox-LDL-triggered superoxide production which suppresses the superoxide dismutase activity and regulates expression of eNOS and LOX-1. Isorhamnetin also inhibits ox-LDL-induced cell apoptosis in THP-1-derived macrophages and also showed anti-atherosclerosis effect in high-fat diet-fed ApoE mice (Luo et al. 2015). The flavonoids present in seed residues of sea buckthorn showed hypolipidemic and hypoglycemic effects by decreasing the total cholesterol level in the blood serum and liver (Wang et al. 2011). The administration of sea buckthorn seed oil to rabbit significantly decreases the LDL-cholesterol and triglyceride, whereas HDL-cholesterol was higher as compared to non-treated animals. It also causes a significant vasorelaxation (Basu et al. 2007). Similarly, Suchal et al. (2014) also reported that pulp oil of sea buckthorn also showed cardioprotective effect in ischemia-reperfusion-induced myocardial infarction in rats. The free radical scavenging and antioxidant activity showed by seed oil administrated to ISO-induced cardiac injury in rats reduces myocardial damage by maintaining biochemical, histopathological, hemodynamic, and ultrastructural perturbations (Malik et al. 2011).

11.4.6 Wound Healing

Sea buckthorn-based preparations are utilized worldwide for treating internal and external wounds of the body, i.e., gastric and duodenal ulcers, skin radiation lesions, and burn of different etiologies. Various researches using clinical trials and animal models showed the protective and curative effects of sea buckthorn against ulcers, wounds and various injuries (Süleyman et al. 2001; Xing et al. 2002a, b; Gupta et al. 2005, 2006, 2008; Upadhyay et al. 2009, 2011). The seed oil of sea buckthorn possesses mitogenic potential and helps in proliferation of keratinocytes and fibroblasts at wound site. The production of free radicals was decreased in burn wounds as endogenous antioxidants were increased with the treatment of seed oil. Sea buckthorn contains palmitoleic acid which plays an important role in wound healing and cellular damage (Bal et al. 2011; Kumar et al. 2011). The supercritical CO_2 extracted seed oil and aqueous leaf extract of sea buckthorn were also found to have wound healing activity in rats (Upadhyay et al. 2009, 2011). The epithelialization time was significantly decreased in burnt areas of sheep with administration of sea buckthorn seed oil for 14 days as compared to untreated areas (Ito et al. 2014). Other researches also showed that endogenous enzymatic and nonenzymatic antioxidants were increased and lipid peroxide level was decreased in wound granulation tissue with the treatment of sea buckthorn (Gupta et al. 2005, 2006, 2008; Upadhyay et al. 2009). Flavone isolated from pulp of sea buckthorn showed positive healing effect on dermal wound of rats (Gupta et al. 2006).

11.4.7 Anti-stress and Adaptogenic Activity

Stress can be expressed as “the pattern of physiological reactions that prepares an organism for action” (Levi 2016) which varies from individual to individual. As culture, industrialization, and overpopulation advance rapidly, stressors (atmospheric pollution, food adulteration, competitive life, synthetic drugs, etc.) of various nature have increased proportionally. The continuation of any form of stress leads to decreased resistance to other forms (Singh and Patra 2019). Adaptogenic herbs are capable of restoring normal tone and function of neurotransmitters challenged during stressful conditions. Adaptogenic herbs differ from other substances in a way as they have a good balance between endocrine hormones and the immune system (Panossian and Wikman 2010) and cooperate the body to sustain optimal homeostasis (Thakur et al. 2015). Plant adaptogens also play a role as smooth pro-stressors that help to decrease the reactivity of host defense system and also reduce the damaging action of various stressors as they increased the basal levels of mediators which are directly linked with the stress response (Singh and Patra 2019). Tulsawani et al. (2010) studied that aqueous extract of *Hippophae rhamnoides* showed antiadaptogenic activity in rats when administrated for 30 days and also at a maximal effective dose 75 mg/kg body weight was nontoxic in rats. The hypoxia-induced transvascular permeability in the lungs of rats was restricted with the administration of leaf extract of sea buckthorn as it decreases the water content and fluorescein leakage in the lungs, and protein and albumin content was also decreased in bronchoalveolar lavage fluid (BALF) (Purushothaman et al. 2011). Sharma et al. (2015) showed that *Hippophae rhamnoides* and *Hippophae salicifolia* in vitro antioxidant activity affects their adaptogenic ability when exposed to simulated cold and hypoxia environment. The aqueous extract of both the species showed higher adaptogenic activity against multiple stresses of cold-hypoxia-restraint exposure as compared to alcoholic extract using rat as animal models. The antioxidant status of cold-hypoxia-restraint stressed rats was maintained with pretreatment of aqueous extract of *H.salicifolia* because free radical production, lipid peroxidation, and protein oxidation were significantly decreased in cold-hypoxia-restraint stressed rats (Rathor et al. 2015).

11.5 Conclusion

Sea buckthorn and its various parts, especially fruit, are the significant source of bioactive compounds with great medicinal value. The major bioactive compounds such as polyphenols, flavonoids, vitamins, fatty acids, minerals, etc. make sea buckthorn as an importance source for development of nutraceuticals and functional foods. Several countries exploit the potential of this plant source for improving livelihood and conservation of environment both commercially and ecologically. There is a wide range and rapid increase in experimental data which shows the potential properties and bioactive components of sea buckthorn. In vivo and in vitro studies of sea buckthorn have found cardioprotective properties by a wide range of mechanisms i.e., reducing blood pressure, inhibiting activation of blood platelets, and lipid metabolism modulation. Moreover, more clinical trials involving human subjects are needed for better understanding of the mechanism of extract bioactivity and development of drug formulations through sea buckthorn. Thus, it can be concluded that sea buckthorn is a rich source of natural phenolic compounds that can substitute the synthetic antioxidants and may be a potent source of active and functional compounds for pharmaceuticals and food products.

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Guava (*Psidium guajava*) 12

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Abstract

Guava has long been known as a low-cost nutritionally rich fruit. It forms an important horticultural crop of many countries around the globe and is native to tropical America and Mexico. Presently almost all the food produce is being characterized in terms of phytochemical composition and related antioxidant activity. With regard to this, guava fruit shows promising results as it has been characterized by high concentration of ascorbic acid, polyphenols, flavonoids and carotenoids. In some guava fruit varieties, anthocyanins have also been detected for the very first time, making it an antioxidant-rich fruit. Dietary fibre present in guava fruit is also rich in antioxidants; therefore, it has been used in a variety of value-added food products to retard lipid peroxidation. Pharmacological activities owed to guava fruit make it a potential ingredient in folk medicines used in subtropical areas worldwide. Almost each part of guava plant (fruits, leaves, bark and roots) is rich in bioactive compounds, making it a fruit of choice for the treatment of numerous health problems, majorly being diarrhoea, fever, cough, bad breath, gum problems, constipation, dysentery, gastroenteritis, hypertension, diabetes, pain relief, wounds and other health problems. Apart from this, it also possesses antioxidant, anti-diarrhoeal, antimicrobial, antiviral, anticancer, hypoglycaemic, hepatoprotective, antimutagenic, anti-inflammatory and antiplaque activities. In this chapter, nutritional significance of guava fruit with respect to antioxidant compounds, their characterization and health benefits have been discussed.

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Guava · Antioxidant · Antimicrobial · Antiviral · Anticancer · Hypoglycaemic · Antimutagenic · Anti-inflammatory

Botanical Name Guava is one of the significant crops linked to the genus *Psidium* and belongs to the Myrtaceae family with the scientific name *Psidium guajava* (Joseph and Priya 2011).

12.1 Introduction

12.1.1 History

It is a native fruit crop of both tropical and subtropical countries being indigenous to tropical America and extends from Peru to Mexico (Samson 1986). *P. guajava* was distributed to east across the Pacific by Spanish, and in India and Africa, the fruit was introduced by Portuguese. It is a remunerative fruit that can be used in both fresh and processed forms. The leaves of guava fruit have been used since time immemorial in preparation of tea to cure a number of diseases. In various countries, it is used to treat leucorrhoea, vaginitis and thrush along with other diseases linked with infections caused by *Candida* spp. (Fenner et al. 2006, Ramirez et al. 2007, Oliveira et al. 2010a, b, Van Vuuren and Naidoo 2010). Different parts of fruit are known to have affluent ethno-medicinal history of treating various infections, particularly gastrointestinal disorders.

12.1.2 Production

As per production statistics of guava is concerned, around 6.5 million tonnes of guava was produced in the year 2017 which is the highest among minor tropical fruits (Altendorf 2018). The major guava-producing countries are India, Pakistan, China, Thailand, Brazil, Indonesia, Bangladesh, Philippines and Mexico. The fruit is majorly cultivated in Asia, and among Asian countries, India contributes 56% of total global output in the year 2017. The total guava production in India accounts for 3 million tonnes which is mostly centred towards domestic markets, and only 2100 tonnes of the produced volume is exported to the USA, Kuwait, Saudi Arabia, European Union and Jordan (Altendorf 2018). This presents a huge scope of guava fruit to be exported from India to developed markets where import demand is growing due to increasing immigrants from Asian countries.

12.1.3 Botanical Description

The botanical structure of guava fruit reveals that the fruit belongs to the phylum Magnoliophyta, the class Magnoliopsida and the family Myrtaceae. As per Nwinyi et al. (2008), there are 133 genera and 3800 species of *Psidium guajava* with all parts of it bearing one or the other health benefits. The tree is a small plant but quite hard in nature that can grow up to 7–10 m high and have a shallow root system. It has wide spreading branches with smooth, pale mottled bark (Yan et al. 2006). The leaves on the plants grow in pairs in opposing sides with oval shape (5–18 cm long and 3–8 cm broad) and are characterized by prominent pinnate veins. The white flowers on the guava plants consist of yellow anther and white stamens (Stone 1970). As per Pelea et al. (2016), 67% genotypes of this fruit are available alone in the Caribbean and Latin America to maintain its sustainability, however, germplasm preservation is restricted. Therefore, countries like Mexico, Cuba, Puerto Rico, Costa Rica, India, Brazil and Venezuela make great efforts to preserve its germplasm (Pommer 2012).

Guava fruits are true berry which have pink, white or yellowish coloured flesh with a number of small seeds. The fruit is typically 3–10 cm in diameter with delicate rind. The colour of the fruit ranges from green at immature stage to pale yellow at mature stage with strong characteristic aroma. This aroma is majorly contributed by the presence of α-pinene, ethanol, hexadecanoic acid, (E)-β-caryophyllene and (Z)-3-hexenol (Pino et al. 2001; Chen et al. 2006). The unique characteristic odour of guava fruit is due to the presence of terpenic compounds and aliphatic esters.

12.2 Antioxidant Properties

Antioxidant property of any fruit is interrelated to its chemical structure, activity and the amount available of the phytochemical compounds. The term phytochemicals means ‘plant chemicals’ or secondary metabolites with structures having biologically active sites that contribute to antioxidant potential of food. These secondary metabolites secreted by plants are responsible for much of the disease prevention. Being a nutritionally active fruit, guava forms an important crop for International trade. Each and every part of guava fruit bears medicinal values due to pharmacological activities such as antiseptic effect, treatment of diabetes mellitus, diarrhoea and others (Gutiérrez et al. 2008). The leaves of guava fruit are a fair source of essential oil and rich in tannin, resin, cineol, triterpenes, flavonoids, eugenol, etc. The major components of essential oil as described by Ogunwande et al. (2003) are longicyclene, limonene, terpinyl acetate, α-pinene, β-pinene, isopropyl alcohol and menthol. The other major antioxidant compounds found in different parts of guava fruits are detailed further.

12.2.1 Fruit/Pulp

Guava fruit has long been known for its processing potential into value-added products like jam, jelly, juice, preserves and nectar. The major nutrient present in guava fruit is vitamin C comparable to citrus fruits (Holland et al. 1991). Among minerals, iron, phosphorus and calcium are available in rich quantity. The fruit is, however, low in both energy content (68 Kcal) and protein content (1%) (El-Buluk et al. 1995). Guava fruit has been recognized as a potential source of phytochemicals due to the presence of polyphenols, carotenoids and ascorbic acid. Among antioxidants present in the diet, polyphenols are the most abundant antioxidants, apparently known to have a positive role in the prevention of degenerative diseases related with oxidative stress, particularly cardiovascular, neurodegenerative and cancer-causing diseases. As per Chiari-Andréo et al. (2017), the major phenolic compounds present in the guava fruit are quercetin, kaempferol and schottenol which correlate well with antioxidant properties. Many other components like quercetin, lyxopyranoside, saponin, arabopyranoside, guaijavarin, oleanolic acid and other flavonoids (Arima and Danno 2002; Das 2011; Dweck 2005) have also been characterized in the fruit. The total phenolic content of guava fruit has been found in the range of 170–340 mg/100 g (Thaipong et al. 2006); 148 to 185 mg/100 g GAE in Thailand and Malaysian varieties (Alothman et al. 2009; Patthamakanokporn et al. 2008) respectively.

Apart from polyphenols, red variety of guava fruit contains lycopene, a principal carotenoid responsible for the red colour of the flesh in the fruit. Among all the reported carotenoids, lycopene is considered as the most powerful antioxidant in vitro found in significant amount in humans (Di Mascio et al. 1989). Lycopene and β-carotene are widely present in guava fruit. The lycopene content of tomato usually ranges from 8.8 to 42.0 μg/g (Rao and Rao 2007), while in pink variety of guava, these values are found as high as 54.0 μg/g. As per Correa et al. (2011), the lycopene content of G73RO germplasm of guava was 40.4 μg/g, whereas red variety of guava, Horana, native to Sri Lanka was reported to have 45.3 μg/g of lycopene (Chandrika et al. 2009).

Among antioxidant analyses by DPPH assay between white and red pulp cultivars of guava, a higher antioxidant activity was observed in all the red cultivars of *P. guajava* in comparison to white pulp. Overall, the highest antioxidant activity was reported for maroon guava variety containing anthocyanin followed by pink varieties and least in white varieties (Flores et al. 2015). Thus, polyphenols could be positively correlated with antioxidant activity (Jayaprakash et al. 2008).

Guava fruit is an abundant source of vitamin C that has been documented as potent antioxidant compound to counteract free radicals causing DNA damage and therefore has preventive effect on plasma lipoproteins (Lehr et al. 1995). As per dietary uptake index of vitamin C, guava fruit contributes around 30% of the requirement in human body.

Guava flour developed by freeze-drying of guava pulp was reported to have 143 mg/100 g ascorbic acid and 970 mg GAE/100 g polyphenols. Among polyphenols, flavonoids were found to be in major proportion (957 mg

GAE/100 g) in guava flour (Moreno et al. 2014). The authors state that consumption of 50 g of guava flour and 300 g of fresh fruit is necessary to cover daily ascorbic acid requirement and 100 g fresh fruit and 3 g guava flour to cover average uptake of flavonoids (i.e. 23 mg/day). With respect to phytochemicals present in guava flour, a dose-dependent relationship was observed between radical scavenging activity and concentration of phenolic compounds which renders guava flour to be used as a healthy dietary supplement.

12.2.2 Waste

The waste of guava fruit could be considered as presence of all seeds, skin and pulp after processing into juice. The antioxidant properties of polysaccharide fractions from pink guava pomace were compared to pink guava juice by Kamarazaman et al. (2017) on the basis of DPPH assay in a dose-dependent manner. Three doses (viz. 500, 750 and 1000 μg/ml) were chosen, and it was observed that pink guava pomace showed higher DPPH scavenging activity at 250 μg/m (i.e. 72.63%) of inhibition while DPPH scavenging activity of pink guava juice was 56.91% at 1000 μg/ml dose. The major contributor of this antioxidant property was polyphenolic compounds (Sindi et al. 2014; Sumczynski et al. 2015; Zhang et al. 2015) as higher levels were found in pomace as compared to juice.

Co-products from mango, guava and Barbados cherry after juice processing were assessed for antioxidant activity in terms of DPPH activity, FRAP assay and β-carotene linoleic acid system by Araujo et al. (2014). Guava by-product displayed lower antioxidant activity as compared to mango and cherry co-products in terms of DPPH and FRAP assay but repressed β-carotene oxidation more efficiently than the cherry extract.

12.2.3 Seed

As per Azevêdo et al. (2011), guava processing yields 25% by-products that can be used in animal feeding. The waste index of fresh guava crops has been reported to be 18.05%, and in Brazil alone, around 202 tonnes of guava is processed each year in the form of frozen fruit pulp, and among these, the total waste accounts for 12 tonnes (Uchoa-Thomaz et al. 2014). Fruit processing plants generate massive by-products that have untapped potential of producing value-added ingredients having food applications with financial benefits. Guava seed is known to have appreciable amount of oil. Guava seed oil has been extracted using a supercritical fluid extraction method with best yield (17%) at 30 MPa pressure and 313 K temperature using a co-solvent, ethanol (Castro-Vargas et al. 2011). Guava seed oil can also be extracted using Soxhlet extractor using a suitable solvent. Guava seed oil was characterized to have major proportion of unsaturated fatty acids (87.06%), particularly C18:1, oleic, and C18:2, linoleic acid. Polyunsaturated fatty acids contributed 77% whereas monounsaturated fatty acids made around 10% of the total unsaturated fatty acids found in guava seed oil.

Guava seed powder was prepared and analysed for chemical components and bioactive compounds by Uchoa-Thomaz et al. (2014). As per the authors, guava seed powder is a good source of dietary fibre (63.94 g/100 g) and a sufficient source of protein (11.19 g/100 g). The major minerals present in guava seed powder reported were iron (13.8 mg/100 g) and zinc (3.31 mg/100 g). Among bioactive compounds, ascorbic acid was found to be in good amount (87.44 mg/100 g), total carotenoids around 1.25 mg/100 g and insoluble dietary fibre (63.55 g/100 g). Fontanari et al. (2008) reported 67.00 g/100 g of dietary fibre in guava seeds. Caloric content of guava seed flour was observed to be on a lower side with values ranging from 264 to 268 Kcal/100 g and thus can be used in food products to add value and reduce calorie intake (Abud and Narain 2009).

12.2.4 Peels

Guava fruit with intact skin was reported to have approximately 13% higher total phenolic content and 10% increased ascorbic acid when compared to peeled fruits (Yan et al. 2006), suggesting the significance of guava peel as a potential source of phenols and ascorbic acid (Bashir and Abu-Goukh 2003; Jimenez-Escrig et al. 2001).

As per scientific studies carried out by Musa et al. (2015) on pink guava varieties (viz. semenyih and sungkai), the authors emphasized on consumption of unpeeled whole fruit as they observed highest antioxidant compounds in guava skin. Total ascorbic acid in the skin of both varieties was higher followed by fruit and flesh part. With regard to other phytochemicals, about three times higher phenolic content was observed in skin alone as compared to whole fruit and 3.5 times higher as compared to flesh. It is a well-anticipated fact that at a certain concentration there will be no increase in the scavenging activity when all the DPPH radicals have been consumed by an antioxidant; therefore, a stage comes when the absorbance does not reduce any further and a constant value is achieved. With regard to this, the DPPH assay revealed that skin fractions reacted faster with DPPH radicals and became constant after 2 min whereas the flesh fractions of semenyih reached the constant in 4 min and 12 min for sungkai flesh. Among all the fractions, semenyih skin, sungkai skin and semenyih fruit were equal in antioxidant potential followed by semenyih flesh, sungkai fruit and sungkai flesh on the basis of radical scavenging activity, highlighting the importance of guava peel as a rich source of antioxidant compounds.

12.2.5 Antioxidant Properties of Value-Added Guava Products

Guava powder, a potential source of antioxidant dietary fibre, was incorporated at two varying concentrations (viz. 0.5% and 1%) in sheep meat nuggets to retard lipid peroxidation upon cooking. The total dietary fibre content of guava powder was noted as 43.21%, among which 98% was insoluble dietary fibre. For bioactive compounds, total phenolics were found to be in highest concentration at around 44.04 mg GAE/g. Being a rich source ascorbic acid, the emulsion stability of nuggets containing guava powder however decreased due to reduced pH, resulting in poor binding capacity of the emulsions. In comparison to control samples, guava powder containing nuggets had 40% less TBARS number due to good antioxidant activity over a period of 15 days (Verma et al. 2013).

Processing of guava fruit results in degradation of ascorbic acid, wherein 37% retention has been reported in guava jelly and 79.6% in guava juice (Jawaheer et al. 2003), indicating that severe heat treatment results in higher reduction of ascorbic acid. As per Teixeira et al. (2006), ascorbic acid being a temperature-sensitive nutrient degrades in the matrix and could be most preserved at low temperatures. The authors observed degradation kinetics of guava paste stored at different temperature and light conditions and found that at 5 °C, guava paste retained 69% ascorbic acid whereas at 30 °C retention rates were 57% without light and 46% with exposure to light.

In an attempt to preserve guava fruit for a long time period, different drying methods were assessed for their effect on its antioxidant activity and bioactive compounds (Patel et al. 2016). Among oven-dried, freeze-dried and osmotic-dried guava fruits, freeze-dried guava extracts retained maximum antioxidant activity. Total phenolic content was lowest in osmotic-dried guava fruit that might be due to wet thermal processing resulting in breakdown of phytochemicals due to cellular membrane alteration, leakage due to osmotic effect and alteration as per chemical reactions (Davey et al. 2000). Flavonoids as estimated by $AlCl_3$ colorimetric method were observed to have same trend as phenolic compounds.

12.3 Characterization of the Antioxidant Compounds and Their Biosynthetic Pathways

Antioxidant activities are mainly assessed by both primary and secondary activities. Primary antioxidant properties are assessed by DPPH assay which in turn is expressed as AEAC, IC_{50} values and ferric reducing antioxidant power (FRAP) assay. The secondary activity on the other hand is assessed by metal chelating power. The basic principle underlying DPPH activity is the capacity of fruit extract to lose hydrogen atom to the DPPH radical that leads to bleaching of DPPH solution. Reaction between antioxidants and DPPH reduces it to DPPH-H resulting in absorbance reduction. Discoloration of DPPH solution is directly proportional to the concentration of antioxidants in a food extract (AEAC value) (Moon and Shibamoto 2009; Yan et al. 2006). However, FRAP assay measures the ability of the fruit extract to donate electron to Fe (III). The greater the antioxidant activity, the greater the FRAP value. The ferrous ion chelating (FIC) activity that determines secondary antioxidant activity is measured by absorbance reduction of the iron (II)-ferrozine complex at 562 nm (Carter 1971; Dinis et al. 1994).

Primary antioxidants act by scavenging radicals that hinder chain initiation and break chain propagation and thus can be defined as radical-deactivating antioxidants, whereas secondary antioxidants or preventive antioxidants act by suppressing the formation of free radicals, thereby protecting the system from oxidative damage. In guava fruit, primary antioxidant activity was noted to be predominant as compared to secondary antioxidant activity (Yan et al. 2006) due to high content of total phenols and ascorbic acid.

Polyphenols are a group of chemicals containing multiple phenolic hydroxyl groups and are found abundantly in fruits and vegetables. Among all the polyphenols present, gallic acid is found in highest concentrations in guava fruit and *Geraniaceae* species (Russo et al. 2005).

Lycopene is a principal pigment responsible for coloration of many red fleshed fruits and vegetables. It is a tetrapenic carotenoid present in pink guava varieties having a molecular formula of $C_{40}H_{56}$ containing 2 unconjugated double bonds and 11 conjugated bonds (Fish et al. 2002). It undergoes *cis-trans* isomerization upon interaction with light, temperature and chemicals (Ollanketo et al. 2001). Lycopene is better absorbed in body when accompanied with fats because of its lipophilic nature (Rao and Agarwal 1999).Seven cultivars of guava including both pink and white varieties were characterized for bioactive compounds and antioxidant activity. The authors found ten new compounds in *P. guajava* Thai maroon variety; two of them (viz. delphinidin-3-O-glucoside and cyanidin-3-O-glucoside) that belong to anthocyanin group were reported for the first time in guava fruit. The other pink varieties did not report any anthocyanin content. Among flavonoids, myricetin-3-O-xyloside, myricetin-3-O-arabinoside and isorhamnetin-3-O-galactopyranoside were found as a new compound in guava fruit. Flavonoids as determined by $AlCl_3$ method react with the hydroxyl group or C-4 keto group of the flavones and flavonols. Ortho-dihydroxyl groups attached to the A or B ring of flavonoids form stable complexes upon reaction with $AlCl_3$ to quantify the total flavonoid content of the fruit (Patel et al. 2016).

12.3.1 Biosynthetic Pathway

Fruit maturation plays a vital role in varying antioxidant components in a matured ripened fruit. In the case of guava, ripening of fruit led to increased ascorbic acid content, whereas total phenols decreased upon fruit maturation (Yan et al. 2006). As a result, reduced astringency was observed upon loss of polyphenols in guava fruit upon maturation, and the increase in ascorbic acid content occurred due to starch breakdown to glucose that was further used in biosynthesis of ascorbic acid. The antioxidant activity however decreased with fruit maturation as total phenolic compounds were observed to have higher and positive correlation with antioxidant activity as compared to ascorbic acid. During storage of guava fruits, ascorbic acid was found to increase due to increased respiration resulting in glucose accumulation further used for ascorbic acid biosynthesis (Tudela et al. 2002).

Ascorbic acid, a water-soluble radical scavenger, donates an electron to free lipid radical and itself gets converted to the ascorbate radical to cease lipid peroxidation chain reaction. These ascorbate radicals in turn react in pairs to generate a dehydroascorbate molecule and one ascorbate molecule. Out of these two, dehydroascorbate does not possess any antioxidant activity and with the addition of two electrons can be converted back to ascorbate molecule with the help of enzyme oxidoreductase (Nimse and Pal 2015).

Phenylpropanoid pathway is crucial for synthesis of polyphenols where deamination of phenylalanine or tyrosine amino acid to cinnamic acids takes place that subsequently enters the pathway for polyphenol production. In this biosynthetic route, introduction of one or more hydroxyl groups into the phenyl ring (Castlellano et al. 2012) forms an important step for polyphenol generation. Upon observation of chemical structure of phenolics, it has been noted that the presence of one or more aromatic rings attached to hydroxyl group is responsible for its antioxidant activity due to the H-donating property of hydroxyl groups. This property helps to remove reactive oxygen species and hence interferes the cycle generating new free radicals. The antioxidant property of phenolics can also be ascribed to its potential of hindering enzyme action that produces free radicals (Fukumoto and Mazza 2000; Dewick 2002).

When consumed by the human body, polyphenols are absorbed and undergo phase II metabolism generating glucuronidated, methoxylated and sulphated compounds (Hollman and Arts 2000). Also, human gut contains pre-established microflora that metabolizes polyphenols and produces a variety of metabolites known as phenolic acids which are ascertained to have positive effects on human body (Olthof et al. 2003).

Gallic acid is a widely found polyphenolic compound in guava fruit and has been found to be a better antioxidant than Trolox compound irrespective of polarity. However, it works as an efficient peroxyl radical scavenger in non-polar media by scavenging hydroxyl radicals at diffusion-limited rates while removing hydroperoxyl radicals with rate constants in the order of $10^{(5)}$ $m^{(-1)}$ $s^{(-1)}$. Gallic acid prevents oxidative stress by de-protonation in aqueous solution at particular pH, where its electron transfer capability makes it capable to deactivate reactive nitrogen species (RNS) and reactive oxygen species (ROS) (Marino et al. 2014). As per Chiari-Andréo et al. (2017), antioxidant compounds in guava fruit can be best extracted using ethanol as a solvent.

Flavonoids are known to have potent antioxidant activity and are particularly effective against hydroxyl radicals involved in DNA damage (Russo et al. 2000). Chelating metal ions such as copper or iron are known to boost free radical scavenging capability of flavonoids. These metal ions complexed with flavonoids prevent generation of reactive oxygen species (Zhou et al. 2001; Rubens de Souza and De Giovani 2004; Armida et al. 2005). However, quercetin, one of the major flavonoids found in guava, is quite effective against oxidative damages made by hydrogen peroxides, superoxide anion radicals and hydroxyl radicals to DNA structure (Krishnamachari et al. 2002), but this protective effect depends on the concentration of cupric ions (Jun et al. 2007; Galaris and Evangelou 2002). At lower concentration (≤25 μM), quercetin shows protective effect on DNA, while at higher concentration (≥25 μM), it enhances DNA damage by reactive oxygen species. Therefore, concentration of chelating metal ions helps determine protective and degenerative effects of flavonoids on human body (Nimse and Pal 2015).

White and red varieties of guava are a rich source of carotenoids, and as per Britton (1995), carotenoids act as an effective antioxidant by reacting with free radicals to yield safe products or by interrupting free radical chain reaction. Basically, conjugated double bond structure rich in electrons is responsible to quench singlet oxygen ($^1O_2\cdot$) without degradation. Among all the carotenoids, the ones with nine or more double bonds give highest protection by reducing singlet oxygen (Foote et al. 1970). The reactions between carotenoid (CAR) and free radicals ($R^{\cdot}$) lead to electron transfer or addition reactions as mentioned below:

$$R^{\cdot} + CAR \Leftrightarrow R^{-} + CAR^{\cdot +} \tag{12.1}$$

$$CAR + CCl_3OO^{\cdot} \rightarrow [CAR\text{-}CCl_3OO]^{\cdot} \rightarrow CAR^{\cdot +} + O_2CCl_{3^-} \tag{12.2}$$

$$\begin{aligned} &CAR + CCl_4 \rightarrow CAR^{\cdot} + HCL + CCl3\cdot \\ &R^{\cdot} + CAR(H) \rightarrow RH + CAR^{\cdot} \end{aligned} \tag{12.3}$$

One of the important parameters in governing antioxidant property of carotenoid is oxygen concentration as carbon-centred radicals react readily by addition reactions with oxygen. Overall, three basic mechanisms (i.e. electron transfer (12.1), addition reaction (12.2) (Edge et al. 1997) and hydrogen abstraction (12.3)) are proposed as possible pathway for reactions between carotenoids and free radicals (Dutta et al. 2005). Among these, electron transfer mechanism involves removal of electron from the carotenoid molecule via oxidizing radicals with high redox potential to form carotenoid radical cation (reaction 12.1), whereas addition reactions form carotenoid-adduct radical with subsequent formation of non-radical product upon further reaction. Addition of polar groups (hydroxyl or carbonyl) onto the rings of carotenoid structure decreases its antioxidant potential due to their electron-withdrawing effects due to the reduced number of conjugated double bonds.

12.4 Health Benefits

Guava (*Psidium guajava*) fruit's status of being super fruit is owed to the presence of nutritionally rich macro- and micronutrients such as dietary fibre, pectin, vitamins A and C and folic acid with major minerals such as iron, copper, potassium, manganese, calcium and phosphorus. Because of the pharmacological activities of guava, it is taken as food as well as folk medicine in subtropical areas (Deguchi and Miyazaki 2010). Various fractions of guava plant like leaves, bark, roots and fruits rich in bioactive compounds are employed for the treatment of fever, cough, dysentery, gum problems, constipation, diarrhoea, gastroenteritis, hypertension, diabetes, pain relief, wounds and various health problems. As found to be hepatotonic, guava fruit seems to be good for the digestive system, liver, intestine and heart. It is also good for diabetic patients and those suffering from liver- and kidney-related problems. Lycopene and flavonoids in guava fruit are found to be helpful in curing cancer cells and preventing skin aging. The medicinal properties of guava as recognized by several countries and generations make up a long list of ethnobotanical studies. It shows great versatility, value in use and treatment against various diseases (Gutiérrez et al. 2008; Dakappa-Shruthi et al. 2013).

12.4.1 Anti-diarrhoeal Activity

Anti-diarrhoeal activity of guava fruit juice and leaf extracts has been clinically studied. Significant antibacterial activity has been observed against various bacteria, namely *Staphylococcus*, *Salmonella*, *Shigella*, *Bacillus*, *Pseudomonas*, *Clostridium* and *E. coli*, known to be diarrhoeal causative organisms. Guava leaf extract shows a sedative effect on intestinal muscles which impairs chemical processes and helps in the re-absorption of water in the intestine during diarrhoea. In another study on acute diarrhoeal disease, alcoholic guava leaf extract exhibited tranquilizing effect due to impairment of gastrointestinal chemical release. During diarrhoeal conditions, calcium antagonism inhibits movement of the intestine, thereby reducing capillary permeability of the abdominal cavity; however, quercetin and its derivatives have the ability to affect these smooth muscle fibres and improve conditions.

A clinical study involving 62 infants diagnosed with infantile rotaviral enteritis, guava was found to have good curative effect (Wei et al. 2000). Treatment with guava accelerated the rate of recovery up to 3 days and ceased diarrhoea in a shorter time period than controls. Ojewole et al. (2008) observed that guava leaf aqueous extract protects rodents against severity of castor oil-induced diarrhoea. Guava leaf aqueous extract has been observed to significantly reduce intestinal transit and deferred gastric emptying in rats/mice. Antimotility effect has been observed in guava extract in a dose-dependent manner similar to atropine (1 mg/Kg), leading to reduction of castor oil-induced enteropooling in animals. Like loperamide (10 mg/kg), guava extract significantly delayed in the onset of diarrhoea and also decreased the frequency of defaecation.

12.4.2 Antimicrobial Activity

Among flavonoids, viz. quercetin, its derivatives and morin glycosides, components of leaf and bark extracts of guava showed antimicrobial activity against various gram-negative and gram-positive pathogens such as *Staphylococcus aureus*, *Shigella*, *E. coli*, *Giardia lamblia*, *Vibrio cholera* and *Pseudomonas aeruginosa*. Similar results were reported by Sato et al. (2000), Abdelrahim et al. (2002) and Arima and Danno (2002) upon identification of antibacterial compounds extracted from methanolic extract of guava leaves. The antibacterial compounds morin-3-O-alpha-L-arabopyranoside and morin-3-O-alpha-L-lyxopyranoside showed MIC (minimum inhibitory concentration) at 200 μg/ml against *Salmonella enteritidis* and 250 μg/ml and 300 μg/ml against

Bacillus cereus, respectively. Methanolic and hot water guava extract showed potential activity against *Chaetomium funicola* and *Arthrinium sacchari* strains. Hexane, acetone and methanol extracts of guava (50 mg/ml) showed significant antimicrobial activity against *Trichophyton tonsurans*, *Trichophyton rubrum*, *Cryptococcus neoformans*, *Microsporum canis*, *Candida parapsilosis*, *Sporothrix schenckii* and *Candida albicans* (Abdelrahim et al. 2002).

12.4.3 Antiviral Activity

Guava fruit extract was observed for its antiviral activity against pathogenic viruses of fish and shrimp by Direkbusarakom et al. (1997). Various fish pathogenic viruses (viz. *Oncorhynchus masou* virus (OMV), infectious *haematopoietic necrosis* virus (IHNV) and infectious *pancreatic necrosis* virus (IPNV)) were tested using plaque reduction in CHSE-214 cell lines. Antiviral tests against the shrimp pathogenic virus yellow-head virus (YHV) was also observed. Results confirmed the antiviral activity of guava extract against *haematopoietic necrosis* virus (IHNV), *Oncorhynchus masou* virus (OMV) and yellow-head virus (YHV) but were not found to be much effective for infectious *pancreatic necrosis* virus (IPNV). Efficacy of guava extract was observed against 24 strains of pathogenic bacteria including *Vibrio harveyi* (9 strains), *Vibrio splendidus* (7 strains), *Vibrio parahaemolyticus* (2 strains) and 1 strain of each *Aeromonas hydrophila*, *Vibrio mimicus*, *Vibrio fluvialis*, *Vibrio vulnificus*, *Vibrio alginolyticus* and *Vibrio cholerae*. The MIC of the extract ranged from 625 to 5000 gm/ml against all above pathogenic bacterial strains tested. The authors stated the possibility of using guava extract for the prevention of diseases in fish and shrimp.

12.4.4 Antioxidant Activity

Antioxidant activity of the guava is linked with the presence of the polyphenols and antioxidants like ascorbic acid and carotenoids. Ethanolic extracts (65% and 95%) along with the deionized extracts of the guava fruit demonstrated the hydroxyl radical scavenging effect and lipid peroxidation was inhibited depending on the dose concentration (Wang et al. 2007). Study reported that 50% concentration (EC50) was effective on the hydroxyl radical scavenging effect (0.47, 0.58, 0.63 g/L) and lipid peroxidation inhibition (0.035, 0.18, 0.20 g/L).

12.4.5 Anticancer Activity

Prospective of the guava plant extracts, leaf oil, leaf extract and guava seed were evaluated for its application in the chemotherapy. Numerous cancer cell lines of humans exhibited significant anticancer activities of the extracts, which included prostate, epidermal cancer, colon along with melanoma and leukaemia. Studies by Chen et al. (2010) and Joseph et al. (2010) reported a remarkable reduction in the serum level of prostate-specific antigen (PSA) and a decrement in the size of the tumour in xenograft mouse tumour model after the use of budding guava leaves in a dose concentration of 1.5 mg/mouse/day. High effectiveness of guava leaf essential oil (0.019–4.962 mg/ml) was reported for the reduced growth in the cell lines of human mouth epidermal carcinoma (KB) and murine leukaemia (P388).

12.4.6 Treatment of Cough

Various guava leaf extracts (aqueous, methanol and chloroform) have proven to be effective against the proliferation of different bacteria, and its anti-cough activity can decrease the incidences of cough. Chulasiri et al. (1986) reported that the dose concentrations of 2 mg/kg and 5 mg/kg of the guava aqueous extract were found to be effective against the capsaicin aerosol induced coughing by 35% and 54% in comparison to control sample after an injection period of 10 minutes.

12.4.7 Antidiabetic Activity

Elevated levels of the dietary fibre content of the guava help in the decrement of blood sugar level in the body of diabetic individual. Various studies have been recorded in this regard. Manikandan et al. (2013) studied the percent inhibition of the methanolic extract of guava against α-amylase enzyme and stated about the dose-dependent results of the extracts, where an increased percentage inhibition was recorded from 27.8% to 96.3% (at an extract concentration of 0.2 ml to 1 ml).

Studies conducted by Mukhtar et al. (2006; 2004) reported about the significant hypoglycaemic activity in the alloxan-induced hyperglycaemic rats induced by the guava stem bark ethanolic extract and reported about the insignificant activity in the case of normal and glucose-loaded normal rats. Studies concluded that the oral doses (250 mg/kg) of aqueous plant extract demonstrated significant hypoglycaemic activity in both acute and sub-acute tests.

12.4.8 Hepatoprotective Activity

Aqueous guava leaf extract (250 and 500 mg/kg) demonstrated great hepatoprotective activity in the case of an acute liver injury induced by compounds such as paracetamol, thioacetamide and carbon tetrachloride. These results were compared to the effects induced by a well-known hepatoprotective agent, silymarin (Roy et al. 2006). Confirmed hepatoprotection was reported with the help of the test reports that indicated reduction of the increased serum levels of alanine aminotransferase, bilirubin, aspartate aminotransferase and alkaline phosphatase in the liver tissues.

12.4.9 Uterine Tonic/Vaginal Disorders

Flavonoids in the guava leaves are associated with the anti-inflammatory and estrogenic effects that can be potentially used in the treatment of dysmenorrhoea. Therefore, extracts of guava tree leaves are suggested for uterine haemorrhage (Ticzon 1997). The same extract is also suggested for uterine problems and vaginal wash, especially when there is requirement of an astringent remedy.

12.4.10 Treatment of Plaque

Guava can be used for the treatment of plaque. A study by Prabu et al. (2006) demonstrated about the potential of the guava as an antiplaque agent against the proliferation of *S. mutans* by using the isolated flavonoid compound quercetin-3-O-alpha-L-arabinopyranoside (guaijaverin). Study reported about the successful treatment of plaque using guava.

12.4.11 Spermatoprotective Activity

Numerous studies are performed related to the influence of guava extracts on sperm production. Studies reported that the antioxidants present in the guava are responsible for the increment of the sperm concentration. Akinola et al. (2007) studied the effects of ethanolic extracts of guava leaves on the production and quality of sperms. Study reported about the improvement of sperm parameters in the case of infertile males with oligospermia and non-obstructive azoospermia.

12.4.12 Antimutagenic Activity

Antimutagenic activity of aqueous extract of guava is supported by various studies. Grover and Bala (1993) reported the effectiveness of the aqueous extract of guava in the inactivation of the mutagenicity caused by direct-acting mutagens. Matsuo et al. (1994) also reported an antimutagenic activity of methanolic extract of guava leaf against *E. coli* which is due to the gallocatechin compound present in the extract.

12.4.13 Central Nervous System Effects

Guava leaves in decoction can be used for spasms and cerebral affections as reported by Ticzon (1997). Study observed reduction in the acetylcholine-evoked release by the quercetin, and the process is related to the interaction associated to presynaptic calcium channels. Moreover, in the case of animals (mice), dose-dependent antinociceptive effects were demonstrated by the guava extracts in thermal and chemical tests of analgesia. Another study stated that the guava extracts have the same antinociceptive effect potential as that of the mefenamic acid (non-steroidal and anti-inflammatory drug) and ten times decreased effectiveness of guava extracts when compared to morphine (opioid analgesic).

12.4.14 Spasmolytic Effect

Spasmolytic activity of guava leaves is mainly associated with the presence of quercetin, an aglycone. Quercetin is present as one of the flavanols in the guava leaf extract. Hydrolysation of these compounds by the gastrointestinal fluid leads to increased effectiveness (Lozoya et al. 1994). A clinical study was conducted on the evaluation of effectiveness of the phytodrug (QG-5) manufactured from guava leaf. Study reported about the effectiveness of drug in lowering abdominal pain (Xavier et al. 2002).

12.4.15 Analgesic and Anti-inflammatory Activity

Consumption of the whole guava fruit can be beneficial for the ones suffering from chronic pains because of anti-inflammatory and analgesic properties of guava fruit. Generally, the aqueous extract of guava leaves possesses both these properties. Studies confirmed that the following doses of hexane (20 mg/kg), ethyl acetate (100 mg/kg) and methanol (1250 mg/kg) extracts of guava leaves show the dose-dependent antinociceptive effects (Ojewole 2006; Shaheen et al. 2000).

12.4.16 Treatment of Acne

The antimicrobial activities of guava fruit and guava leaf extracts were studied by Qadan et al. (2005a, b) by using disc diffusion method (zone of inhibition). Further, antibiotics like clindamycin and doxycycline and tea tree oil were used to compare the demonstrated antimicrobial properties. The study also concluded the beneficial effects of guava and its leaf extract for the treatment of acne.

12.4.17 Antiproliferative Activity

Extracts of the guava leaves demonstrated antiproliferative activity by inhibiting the catalytic activity of prostaglandin endoperoxide H synthase (PGHS) isoforms (Kawakami et al. 2009). Studies conducted on the antiproliferative activities of Thai medicinal plants on the cells of epidermal carcinoma and murine leukaemia of human mouth reported that the extracts of guava leaves exhibit 4.37 times more antiproliferative activity than vincristine (Manosroi et al. 2006).

12.4.18 Antipyretic Activity

Olajide et al. (1999) reported an antipyretic effect of methanolic extract of guava leaves. Another study by Joseph et al. (2011) concluded that the aqueous extract of guava in the dose 200 mg/kg produced antipyretic effects for 60 min like aspirin.

12.4.19 Contractile Effect

Magnesium helps to relax nerves and muscles of the body. Guava is a rich source of magnesium and serves as a natural muscle and nerve relaxant. Water extract of guava leaf (0.25–2 mg/ml) helps in the contraction of aorta rings. Guava also helps in the activation of α-adrenoceptor and has contributions in calcium ion channel (Olatunji-Bello et al. 2007).

12.4.20 Anti-hypotensive Effect

Guava has shown significant anti-hypotensive effects by reducing hypertension and heart rates. Lower blood pressure was observed in the mammalian experimental animal model, contributed by the water extract of guava. Studies conducted in hypertensive and Dahl salt-sensitive rats reported that reduction in blood pressure and heart rate is dependent on the concentration and 50–800 mg/kg of water extracts was concluded as the effective doses (Ojewole 2005).

12.4.21 Anti-malarial Activity

Guava fruit juice, leaves and stem bark are known for anti-malarial activity and used as effective remedies for the treatment of dengue fever. At least three times a day is recommended for desired results. Guava leaves can be infused along with teas for treatment purposes. These can also be used as a part of the pot herb used in steam treatment for malaria (Nundkumar and Ojewole 2002). The extract of stem bark guava plant contains flavonoids, anthraquinones, terpenoids and secoiridoids which are found to have anti-malarial activities and effective for the prophylaxis and treatment of malaria.

12.4.22 Oral Care

In the southern region of Nigeria, the twigs of guava plant are used as chewing sticks. These are comprised of bioactive components such as alkaloids, saponins, tannins and flavonoids which are responsible for effective oral care treatment. These chewing sticks are found to be very effective, efficient and reliable when used without toothpaste when cleaning teeth (Okwu and Ekeke 2003). Using twigs as chew sticks usually resulted in strong, fresh, clean teeth without dental plaque caries.

12.4.23 Others

Guava keeps body lipid content in normal range and acts as a cardioprotective agent because of associated arjunolic acid and flavonoids (Kumari et al. 2013). As reported by Garcia Conde et al. (2003), extracts of guava leaves depress myocardial inotropism. Kaileh et al. (2007) documented immune-modulatory activities derived from guava extracts (55 μg/ml). Flowers of guava plant can be used as a poultice for conjunctivitis, and the crushed leaves of guava are used for the treatment of rheumatism in India (Ayensu 1978). Antibacterial properties possessed by the guava fruit can help in drainage of toxins and harmful bacteria out of the body. Pink guavas hold double the amount of lycopene present in tomatoes which can protect human skin from environmental pollution and harmful ultraviolet radiations. As reported by Batick (1984) and Khan and Ahmad (1985), pulmonary diseases, asthma attacks and bronchitis could be also treated using teas made from guava leaves. Ethanolic extract of guava has immune-modulating and immune-stimulating properties which can be used as curing agent in stress-related disorders. These anti-stress and adaptogenic activities of extract are also associated with enhancement of homeostatic mechanisms (Lakshmi and Sudhakar 2009).

12.5 Conclusion

Guava, a super fruit, is widely consumed for its good taste and nutritional benefits throughout the world. It contains an array of nutrients and has been used for treatment against a wide range of diseases since ancient times. The fruit contains sufficiently great amounts of bioactive components, making it an antioxidant-rich crop. Potential uses of the crop for its pharmacological activities have been extensively studied, and the results indicate that it possesses potent antimicrobial, antiviral, anti-diarrhoeal, anticancer, antidiabetic, antioxidant, hepatoprotective, antimutagenic and various other properties. High medicinal values of the guava crop have opened up new paths of inventions in the field of therapeutic applications. Further studies are required to find the actual mechanism behind the pharmacological activities of guava.

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Muntingia calabura

13

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Abstract

Muntingia calabura, a fruit present in North and South America and some parts of Asia due to its adaptability to extreme conditions of climate and soil, has been studied for its potential health benefits in recent years. Extracts obtained from its leaves, fruit, stem, and bark have been subjected to qualitative and quantitative analyses for their therapeutic strengths. The biological functionalities of these extracts such as antioxidant, antidiabetic, antihypertensive, and anti-inflammatory, amongst others, have been confirmed with various tests in vivo and in vitro. This chapter describes the geographical distribution of *Muntingia calabura*, along with its nutrient and botanical information. More emphases are placed on the antioxidant profile of the plant based on the phytochemicals available in extracts obtained from its parts and their bioactivities.

Keywords

Muntingia calabura · Bioactivities · Antioxidants · Antidiabetic · Antihypertensive

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13.1 Introduction

Muntingia calabura L., the sole species in the genus *Muntingia*, is an evergreen flowering plant that belongs to the Elaeocarpaceae family. This plant is native to tropical South America, Central America, the Greater Antilles, Southern Mexico, Trinidad, and Saint Vincent, but due to its good soil and climate adaptation, it has been widely cultivated in several tropical countries including Brazil, India, China, Malaysia, Indonesia, and the Philippines. It is a pioneer fast-growing tree that grows fast even in poor soils and can tolerate acidic and alkaline conditions and drought. This plant has also been cultivated as decorative tree on roadsides, streets and public squares. Calabura tree bears small red color fruits, commonly called Jamaican cherry, Panama berry, or Singapore cherry in English, Kerukupsiam in Malaysia, and Pau-seda or calabura in Brazil. Fruiting of plant continues throughout the year with peak season from April to July. The fruit is sweet in taste, musky with a fig-like flavor, and filled with exceedingly minute seeds. Although these local fruits are unavailable in Indian markets, they are widely eaten by people of rural India (Sani et al. 2012; Zakaria et al. 2011).

13.1.1 Botanical Information

Muntingia calabura is a fast-growing small tree (7.5–12 m) of slender proportions with tiered and nearly horizontal drooping branches, serrated evergreen leaves (5–12.5 cm long), slightly malodorous flowers (1.25–2 cm wide) with five green sepals and five white petals and many prominent yellow stamens. These flowers give rise to abundant round-shaped light red fruits (1–1.25 cm wide), with thin, smooth, tender skin and light-brown juicy pulp, very sweet and musky, fig-like flavor, and exceedingly tiny (0.5 mm) yellowish seeds. The fruit has a sweet and unique flavor, which pleases the human taste and attracts birds. *Muntingia calabura* is a climacteric fruit that can ripen fully if they are harvested at completion of their growth period.

13.1.2 Nutritional Composition

Muntingia calabura fruits are eaten fresh and they are mostly consumed as home-made preparations, but these berries could have great potential for use in the food industry and as functional food due to its physicochemical properties and high content of antioxidant compounds (Lin et al. 2017b). The nutrient composition of *M. calabura* is shown in Table 13.1.

Table 13.1 Nutrient composition of *M. calabura*

Nutrient	% composition
Carbohydrate	14.64
Protein	2.64
Lipid	2.34
Fiber	1.75
Minerals	1.28
Titratable acidity	0.11

Source: Pereira et al. (2018)

13.2 Biofunctionality of *M. calabura* Parts

13.2.1 Fruits

The fruit of *M. calabura* Linn. has been scientifically proven to possess diverse biological and health benefits such as anti-inflammatory, antipyretic, antinociceptive, and antioxidative due to the presence of diverse bioactive phytochemicals such as flavonoids, vitamins, and phenolics. Their antioxidative properties seem to be more prominently studied simply by the mechanism of radical scavenging activities using in vitro assays such as 2,2-diphenyl-1-picrylhydrazyl (DPPH), superoxide anion of nicotinamide adenine dinucleotide (NADH), and nitric oxide and reactions such as ferrous ion chelating activity and inhibition of lipid peroxidation or by analytical evaluation of the quantities of antioxidants in its extracts.

Pereira et al. (2018) conducted a study on the extensive evaluation of phytonutrients from *M. calabura*. Ultra-high-performance liquid chromatography triple quadrupole mass spectrometry (UHPLC-MS/MS) was adopted for the analysis of phenolic compounds, and the major phenolic compounds identified were cyanidin-3-O-glucoside (171 μg/g dw) and gallic acid (5325 μg/g dw). Polyphenol categories such as flavonols (epigallocatechin, gallocatechin, catechin, and epicatechin), flavanone (naringenin), flavonols (quercetin and rutin), hydroxybenzoic acids (gentisic acid, vanillic acid, 4-hydroxybenzoic acid, gallic acid, and protocatechuic acid), and hydroxycinnamic acids (p-coumaric acid, caffeic acid, ferulic acid, sinapic acid, and chlorogenic acid) were found in analytical quantities.

Lin et al. (2017a, b) performed a similar study and obtained results following the same inclination with the identification of 11 phenolic acids with their concentration in milligram per gram of the ethanolic extract of the fruit, namely, rosmarinic acid (0.17 ± 0.01), p-anisic acid (1.08 ± 0.07), syringic acid (1.49 ± 0.09), sinapic acid (2.13 ± 0.07), ferulic acid (0.65 ± 0.03), p-coumaric acid (4.12 ± 0.17), caffeic acid (1.12 ± 0.08), p-hydroxybenzoic acid (2.17 ± 0.09), gentisic acid (6.72 ± 0.24), gallic acid (9.11 ± 0.42), and vanillic acid (1.32 ± 0.07), and 4 flavonoids, namely, luteolin (0.12 ± 0.01), diosmin (0.23 ± 0.01), rutin (1.01 ± 0.05), and epicatechin (0.87 ± 0.03) mg/g extract, respectively.

Preethi et al. (2010) carried out an investigation on diverse antioxidant properties of *M. calabura* fruit using multiple extracts. Extraction solvents such as methanol, butanol, ethyl acetate, chloroform, and hexane were used to check the antioxidant potential with reference to its reducing power, 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity, ferric ion chelation potential, nitric oxide, and superoxide anion scavenging strength. The half maximal inhibitory concentration (IC50) values in g/mL showed that the methanolic extract was most potent for all activities with 90 ± 0.04 for DPPH radical, 80.26 ± 0.08 for iron chelation, 187 ± 0.04 for nitric oxide, and 79.2 ± 0.04 for superoxide tests, respectively.

Gomathi et al. (2013) analyzed the polyphenolic extract of *M. calabura* fruit for its phytonutrient composition and reported that it contained anthocyanins (82.4 mg CGE/g extract), total phenolics (121.1 mg GAE/g extract), vitamin E (14.7 mg TE/g extract), flavonoids (173.2 mg RE/g extract), and vitamin C (33.6 mg AAE/g extract). Further studies for volatile constituents showed the presence of campesterol (4.47%), stigmasterol (7.20%), γ-sitosterol (11.15%), n-hexadecanoic acid (11.97%), phytol (26.26%), and cyclopropaneoctanoic acid (10.26%). On the basis of inhibition of nitric oxide and hydroxyl and DPPH radical scavenging potentials, half maximal inhibitory concentration (IC50) values of 15.01 ± 1.2 μg/mL, 24.9 ± 3.3 μg/mL, and 10.6 ± 0.6 μg/mL, respectively, were obtained from in vitro analyses.

13.2.2 Leaves

The leaves of *M. calabura* have been described as oppositely and alternately arranged, adherent, and simple, with shape varying from broadly oblong-lanceolate to oblong-ovate, with 1–6 cm width, and 4–15 cm by length (Lim 2012).

M. calabura leaves are perhaps its most functional vegetative part with established effects of antiulcer, antipathogenic, antidiabetic, antioxidative, antipyretic, cardioprotective, and antinociceptive benefits (Mahmood et al. 2014). Flavonoids, chalcones, tannins, saponins, steroids, and triterpenes are amongst the phytochemicals that have been identified in its leaves.

Chen et al. (2007) conducted a scrutinous examination of the phytochemical composition of *M. calabura* leaves and reported the discovery of one flavanone and two dihydrochalcones along with several other already discovered polyphenolic compounds.

Several studies have been conducted to examine the antioxidant activity of *M. calabura* leaf extracts using innovative analytical techniques. Buhian et al. (2016a) conducted a thin-layer chromatography for the evaluation of the DPPH radical scavenging ability of obtained methanolic extracts. Subsequent to vanillin-sulfuric acid spray, the chromatographic spots were surveyed under two distinct ultraviolet rays (at 366 and 254 nm, respectively) and visible light. Their results affirmed the presence of multiple antioxidative bioactives in the extract.

Rahmawati et al. (2018) conducted an investigation regarding the intracellular and in vitro antioxidative potential of the methanolic extract (MLME) of

M. calabura leaves. In their study, 3T3 fibroblast cells were subjected to ultraviolet-induced (UVB at 260–320 nm) oxidative stress, and their results showed that the MLME had a significant impact at the intracellular level. A 3.030 μg/mL IC50 value was obtained for the DPPH scavenging in vitro analysis.

Md Nasir et al. (2017) performed a novel in vivo study on the antioxidative action of the methanolic extract of *M. calabura* leaves against oxidative stress in the colon of laboratory animals. A critical analysis of the extract with ultra-high-performance liquid chromatography-electrospray ionization/mass spectrometry (UHPLC-ESI-MS/MS) confirmed the presence of some flavonoids such as pinocembrin, ferulic acid, gallic acid, and rutin which were associated with the inhibition of the colonic oxidative stress.

Zakaria et al. (2011) performed a comparative evaluation of chloroform, methanolic, and aqueous extracts of *M. calabura* leaves regarding their total phenolic contents and DPPH scavenging activities. In all tests, the chloroform extracts were least active while the methanolic extract was superlative for the DPPH scavenging activity, and the aqueous extract had the highest readings for total phenolic content.

13.2.3 Stem Wood and Bark

Antioxidants have been isolated from these portions of *Muntingia calabura*.

Kuo et al. (2014) isolated multiple novel and known antioxidant bioactive compounds from the methanolic extract of dried *Muntingia calabura* bark. Three new polyphenols including one dihydrochalcone, one flavone, and one biflavan were isolated, namely, 2′,β-dihydroxy-3′,4′-dimethoxydihydrochalcone, 4′-hydroxy-7,8,3′,5′-tetramethoxyflavone, and decamethoxy-5,5″-biflavan, respectively. Other compounds isolated include β-sitosterol, β-sitostenone, gallic acid, quercetin, ferulic acid, 7,8,3′,4′,5′-pentamethoxyflavone, 5′-hydroxy-7,3′,4′-trimethoxyflavanone, 7-hydroxyflavanone, 5-hydroxy-7-methoxyflavone, 8,5′-dihydroxy-7,3′,4′-trimethoxyflavan,‘5’-hydroxy-7,8,3′,4′-tetramethoxyflavan, and 8,5′,8″-trihydroxy-7,3′,4′,7″,3‴,4‴,5‴-heptamethoxy-5,5″-biflavan.

Chen et al. (2004) in a study regarding the cytotoxicity of compounds in *Muntingia calabura* bark extracts isolated 15 polyphenolic compounds, out of which two (flavones) were found to be novel. The novel flavones are 8,4′-dihydroxy-7,3′,5′-trimethoxyflavone and 8-hydroxy-7,3′,4′,5′-tetramethoxyflavone. Other identified compounds include 6,7-dimethoxy-5-hydroxyflavone, 1-hexacosanol, 3,5-dihydroxy-6,7-dimethoxyflavone, 1-tetracosanol, tetracosylferulate, β-sitosterol, 6′-hydroxystigmast-4-en-3-one, β-sitostenone, 5′-hydroxy-7,8,3′,4′-tetramethoxyflavan, 5,7-dimethoxyflavone, and 3-hydroxy-1-(3,5-dimethoxy-4-hydroxyphenyl) propan-1-one.

Krishnaveni et al. (2015) conducted an extensive compositional analysis of *Muntingia calabura* bark using its aqueous extract. Amino acids were reported to be 406.66 ± 2.88 mg/g, total protein content 423.33 ± 2.88 mg/g, and total carbohydrate 355.00 ± 0.00 mg/g. The aqueous extract showed positive results for the presence of anthraquinone and alkaloids and its antioxidant profile measured qualitatively and quantitatively. The total flavonoid content was reported to be 376.66 ± 5.77 mg/g, and the total phenolic content was found to be in a higher quantity of 386.66 ± 5.77 mg/g. Multiple antioxidant tests of hydrogen peroxide and nitric oxide scavenging potentials, metal chelation, total antioxidant, and reducing power were conducted, and values of 92.88 ± 0.14, 351.66 ± 14.43, 495.0 ± 8.66, 326.66 ± 2.88, and 311.66 ± 2.88 mg/g, respectively, were reported.

13.3 Health Benefits

The common health benefits are shown in Table 13.2.

13.3.1 Antidiabetic

Diabetes is a collective name for metabolic syndromes characterized by a spike in blood sugar amounts over elongated time periods. Known categories of diabetes include cystic fibrosis-related diabetes and maturity onset diabetes of the young (MODY) and neonatal diabetes which are both broadly classified as monogenic diabetes, gestational diabetes, and type I and type II diabetes.

Diabetes resulting from cystic fibrosis is the most typical comorbidity in patients involving a sticky and viscous mucus, initiating scars in the pancreas and consequently inhibiting it from synthesizing sufficient quantities of insulin for proper functioning of the body, and giving it the clinical similarity of type I and type II diabetes (Moran et al. 2010).

Maturity onset diabetes of the young (MODY), though commonly confused with type I and type II diabetes, is caused by genetic mutations which alters the body's synthesis of insulin. Though with mild symptoms, such mutations are potential enough to cause remarkable damage to bodily tissues.

Gestational diabetes, as the name implies, occurs during pregnancy in women with a strong possibility of subsiding subsequent to delivery and yet with the likelihood of reoccurring as type II diabetes later on. Type I and type II diabetes are the most prominently known kinds of diabetes entailing the lack of insulin and the inability to make use of synthesized insulin, respectively.

Accordingly, the extracts obtained from the leaves of *Muntingia calabura* have been studied for their antidiabetic activities. Aligita et al. studied the antidiabetic potential of the aqueous extracts of *Muntingia calabura* L. leaves in vivo. Their study involved two distinct models in analogy with type I and type II diabetes, with the first model investigating the dose-dependent effects of the extracts on the synthesis of insulin and the second model following the course of how the extracts affected insulin resistance in the tested laboratory animals, and the outcome of the first group tests was measured by the amounts of blood fasting glucose while the second was measured by the constant insulin tolerance values. For the first model group, a reduction of fasting blood glucose by 29, 22, and 13% was observed for

Table 13.2 Therapeutic benefits of extracts obtained from *M. calabura*

Biofunctionality	Plant part	Extract(s)	Study description	Results	References
Anticarcinogenicity	Leaves	Methanolic extract	To study the chemoprevention effects of MEMCL against azoxymethane (AOM)-induced colon cancer and to examine the involvement of endogenous antioxidants	Significant anticarcinogenic activity, indicated by a decrease in the total aberrant crypt formation; antioxidant activity by increasing the colon tissue antioxidant markers (i.e., superoxide dismutase (SOD), catalase (CAT), and glutathione (GSH)) and reducing the oxidant marker: malonaldehyde (MDA) levels	Md Nasir et al. (2017)
Antinociceptive activity	Leaves	Methanolic extract	To determine the antinociceptive activity of methanol extract of *M. calabura* leaves (MEMC) in vivo and to elucidate the possible mechanism of antinociception involved	Antinociceptive activity involves activation of the peripheral and central mechanisms and modulation via, partly, the opioid receptors and NO/cGMP pathway	
Antioxidant activity	Peel	Methanol-in-water and magnetic stirring as extraction methods	Antioxidative evaluation by HPLC-DAD and UPLC-ESI-MS/MS analysis for DPPH radical, ORAC, ABTS cation radical, and FRAP assays and total phenolic contents by different extraction conditions	The developed HPLC-DAD method was efficient for the determination of phenolic compounds, with recoveries in the range of 72–107% and precision values ≤4%, with exception for chlorogenic acid. Gallic acid was determined at the highest concentration levels, followed by myricetin, ferulic acid, and vanillic acid. All five proposed phenolic compounds were identified in calabura peel samples by UPLC-ESI-MS/MS	Rotta et al. (2017)

(continued)

Table 13.2 (continued)

Biofunctionality	Plant part	Extract(s)	Study description	Results				References
Antipathogenic	Leaf, bark, and fruits	Aqueous and methanol extracts	Test for bioactive phytochemicals and activity against bacterial strains (*Bacillus cereus*, *Klebsiella pneumoniae*, *Micrococcus luteus*, *Proteus vulgaris*, *Pseudomonas aeruginosa*, and *Serratia marcescens*) and fungal strains (*Aspergillus oryzae*, *Fusarium* sp., and *Penicillium* sp.)		Leaf	Bark	Fruit	Sibi et al. (2012)
				Glycosides	√	√	√	
				Flavonoids	√	×	√	
				Phlobatannins	√	√	×	
				Saponins	×	×	×	
				Tannins	√	√	√	
				Terpenoids	√	√	×	
					Aqueous, methanolic			
					Leaf	Bark	Fruit	
				Bacillus cereus	×,√	√,√	×,√	
				Klebsiella pneumoniae	×,×	×,×	×,×	
				Micrococcus luteus	√,√	√,√	√,√	
				Proteus vulgaris	×,×	×,×	×,×	
				Pseudomonas aeruginosa	√,√	√,×	×,√	
				Serratia marcescens	×,×	×,×	×,√	
				Aspergillus oryzae	×,√	×,×	×,×	
				Fusarium sp.	×,√	×,√	×,×	
				Penicillium sp.	×,√	×,√	×,×	

Antiulcer activity	Leaves	Methanolic extract	Evaluation of the antiulcer activity of MEMC in absolute ethanol- and indomethacin-induced gastric ulcer rat models	No toxicity resulting from administered dosage in the rats. Methanolic extract imparted gastroprotective activity in the ethanol- and indomethacin-induced ulcer models dose dependently. Histological evaluation supported the observed antiulcer activity of extracts	Balan et al. (2013)
Antioxidant activity	Fruit		Evaluation of soluble carbohydrates, volatile and phenolic compounds, and antioxidant activity	UHPLC-MS/MS analysis revealed gallic acid (5325 μg/g dw) and cyanidin-3-O-glucoside (171 μg/g dw) as the main phenolic compounds, followed by gentisic acid, gallocatechin, caffeic acid, and protocatechuic acid. In addition, gallic acid was found mainly in esterified (2883 μg/g dw) and insoluble-bound (2272 μg/g dw) forms. Free and glycosylated forms showed highest antioxidant activity due to occurrence of flavonoids (0.28–27 μg/g dw) in these fractions, such as catechin, gallocatechin, epigallocatechin, naringenin, and quercetin	Pereira et al. (2018)
Antioxidant and anti-inflammatory activities	Leaves	Crude methanol extract fractionated with petroleum ether (PEF), ethyl acetate (EAF), and distilled water (AQF)	Determination of the prophylactic effect of the crude methanolic fractions obtained against ethanol-induced gastric lesion in rats and the involvement of antioxidants and anti-inflammatory mediators	All fractions improved gastric ulceration in ethanol-induced rats, except AQF at its highest dose. These fractions, owning to its high antioxidant content and radical scavenging activity, were found capable of suppressing the formation of gastric lesions. Flavonoids and gallic acid were found present and imparted protection against gastric damages	Balan et al. (2015)

(continued)

Table 13.2 (continued)

Biofunctionality	Plant part	Extract(s)	Study description	Results	References
Gastroprotective activity	Leaves	Methanolic extract	Evaluation of the mechanism (s) of gastroprotective effect of methanol extract of *Muntingia calabura* leaves (MEMC) using the pylorus ligation-induced gastric ulceration in rats	Significant reduction in volume of gastric content and increase in mucus content of laboratory rats. High antioxidative and anti-inflammatory activities due to the high concentration of tannins and saponins	Zakaria et al. (2015)
Anti-inflammatory activity	Fruit	Methanolic extract	Reduction of carrageenan-induced edema in vivo	Extracts of 100–300 mg/kg imparted anti-inflammatory effects with no observed toxicity or behavioral abnormality	Preethi et al. (2012)
Anti-inflammatory activity	Fruit	Ethanolic extract	Inhibition of lipopolysaccharide-induced pro-inflammatory mediators in macrophages	Suppression of the lipopolysaccharide (LPS)-stimulated expressions of inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2), as well as the productions of nitric oxide (NO), prostaglandin E2 (PGE2), and pro-inflammatory cytokines (tumor necrosis factor-α (TNF-α), interleukin (IL)-1ß, and IL-6) in RAW264.7 macrophages	Lin et al. (2017a, b)
Antiproliferative and antioxidant activities	Leaves	Aqueous, chloroform, and methanol extracts	Inhibition of MCF-7, HeLa, HT-29, HL-60, and K-562 cell lines, DPPH radical and superoxide scavenging potentials	All extracts (20, 100, and 500 μg/ml) were found to possess antioxidant activity when tested using the DPPH radical scavenging and superoxide scavenging assays with the methanol extract, followed by the aqueous and chloroform extracts exhibiting the	Zakaria et al. (2011)

				highest antioxidant activity in both assays. The total phenolic contents for the aqueous, methanol, and chloroform extracts were 2970.4 ± 6.6, 1279.9 ± 6.1, and 2978.1 ± 4.3 mg/100 g gallic acid, respectively	
Antioxidant activity	Fruit	Hexane, chloroform, ethyl acetate, butanol, and methanolic extracts	Phytonutrient and antioxidant evaluation	The total phenolics ranged from 1486 ± 0.028 mg GAE/100 of fresh mass (FW) to 358 ± 0.020 mg GAE/100 of fresh mass (FW). Results showed high levels of antioxidant activity of the fruit extracts	Preethi et al. (2010)
Antioxidant and anti-inflammatory activities	Fruit	Solvent mixture (methanol/acetone/water, 3.5:3.5:3 v/v/v)	To evaluate the potential anti-inflammatory (in vivo) and antioxidative effects (in vitro) of the polyphenolic extract	Extract content: vitamin C (33.6 mg AAE/g extract) and E (14.7 mg TE/g extract), total phenolics (121.1 mg GAE/g extract), flavonoids (173.2 mg RE/g extract), and anthocyanins (82.4 mg CGE/g extract), volatile compounds such as phytol (26.26%), n-hexadecanoic acid (11.97%), cyclopropaneoctanoic acid (10.26%), γ-sitosterol (11.15%), stigmasterol (7.20%), and campesterol (4.47%). DPPH radical scavenging activity (IC50 10.6 ± 0.6 μg/mL) and effectively inhibited hydroxyl (IC50 24.9 ± 3.3 μg/mL), and nitric oxide (IC50 15.01 ± 1.2 μg/mL) radicals in vitro. Remarkable anti-inflammatory activity in vivo	Gomathi et al. (2013)

(continued)

Table 13.2 (continued)

Biofunctionality	Plant part	Extract(s)	Study description	Results	References
Antioxidant activity	Fruit	Ethanol extract	Determination of DPPH radical scavenging activity, suppression of low-density lipoprotein (LDL) oxidation, Trolox equivalent antioxidant capacity (TEAC), and phenolic contents	The effective compounds gallic acid and 1,2-benzenedicarboxylic acid diisooctyl ester with good activity for suppressing human LDL oxidation were isolated; their quantities were 3.76 (gallic acid) and 4.62 (1,2-benzenedicarboxylic acid diisooctyl ester) mg/g, respectively	Lin et al. (2017a, b)
Gastroprotective effect	Leaves	Ethyl acetate fraction (EAF) obtained from the crude methanolic leaves	Investigation of the mechanism of gastroprotection using pylorus ligation-induced gastric lesion rat model	Quercetin and gallic acid were identified in the EAF. In pylorus ligation model, EAF was found to prevent gastric lesion formation. Volume of gastric content and total protein content reduced significantly while free and total acidity reduced in the doses of 250 and 500 mg/kg. EAF also augmented the mucus content significantly	Zakaria et al. (2016)
Bioactive phytochemicals and antimicrobial activity	Leaves and stems	Ethanol extract	Determination of antibacterial and antifungal activities of the extracts using the disc diffusion assay with phytochemical analyses	*Pseudomonas aeruginosa* (*P. aeruginosa*), *Salmonella typhimurium*, *Staphylococcus aureus* (*S. aureus*), *Bacillus subtilis*, and *Candida albicans* (*C. albicans*), with minimal activity against *Escherichia coli*. The extracts showed the highest activity against *C. albicans*, *S. aureus*, and *P. aeruginosa*. Phytochemical screening revealed the presence of sterols, flavonoids, alkaloids, saponins,	Buhian et al. (2016a, b)

				glycosides, and tannins in the leaf extract; however, no triterpenes were detected. In the stem extract, triterpenes were detected along with relative amounts of flavonoids, saponins, glycosides, and tannins. Alkaloids and sterols were absent in the stem extract	
Inhibitory activities on neutrophil pro-inflammation	Stem wood	Methanolic extract	Isolation of bioactive compounds	Biflavans, flavonoids, and a dihydrochalcone. Other bioactive compounds include 5-hydroxy-7-methoxyflavone, quercetin, and (2S)-7-hydroxyflavanone which exhibited potent inhibition of fMLP-induced superoxide anion generation by human neutrophils, with IC50 values of 1.77 ± 0.70, 3.82 ± 0.46, and 4.92 ± 1.71 μM, respectively	Kuo et al. (2014)
Hepatoprotective activity	Leaves	Aqueous partition of methanol extract	To evaluate the hepatoprotective activity of partitions and mechanisms of action against paracetamol (PCM)-induced liver injury	The aqueous methanolic extract was found to exert distinct hepatoprotective activity against paracetamol (PCM)-induced liver injury via the activation of endogenous antioxidant and LOX-mediated systems. Hepatoprotective activity of AQMC could be attributed partly to the direct action of hepatoprotective-bearing flavonoids, such as gallic acid and quercetin, and to the indirect action of antioxidant- and/or anti-inflammatory-bearing flavonoids, such as kaempferol, myricetin, pinostrobin, and pinocembrin	Zakaria et al. (2018)

(continued)

Table 13.2 (continued)

Biofunctionality	Plant part	Extract(s)	Study description	Results	References
Anticancer activity	Fruit	Ethanol extract	Study on protection against nickel (Ni)-induced vascular endothelial growth factor (VEGF) expression in hepatocellular carcinoma (HepG2) cells	Contained 4 flavonoids (epicatechin, rutin, diosmin, and luteolin) and 10 phenolic acids (gallic acid, gentisic acid, p-hydroxybenzoic acid, vanillic acid, p-coumaric acid, ferulic acid, sinapic acid, syringic acid, p-anisic acid, and rosmarinic acid). Extract found to possess the potential to lower liver cancer risk in the Ni-polluted environment by suppressing VEGF expression	Lin et al. (2018)

administered doses of 400, 200, and 100 mg/kg, respectively. The constant insulin tolerance values increased in a dose-dependent by 1.13, 1.57, and 2.31 for 100, 200, and 400 mg/kg administrations, respectively. A similar study was conducted by Herlina (2018)) using the ethanolic extracts of the leaves and measuring their dose-dependent antidiabetic effects in vivo. Their results showed a decrease in blood glucose level of tested rats by 35.66, 32.16, and 28.90% for doses of 260, 120, and 65 mg/kg of body weight, respectively.

13.3.2 Anticancer

Cancer is one of the leading noncommunicable diseases on the global scale, especially with fatal end result. It has been described as a collection of over 100 diseases with the common feature of proliferative growth of cells, culminating into tumor lumps in the body. They are popularly found in the breasts of women, prostate glands of men, kidney, lungs, liver, and colon and possess physiological characteristics of unstopping growth trend, evasion of natural suppressants for the growth of body cells, initiation of metastasis and angiogenesis, and an obnoxious defiance to the natural order of cellular apoptosis. The common therapies for cancer management (surgery, chemotherapy, and radiotherapy) have underlying disadvantages of high cost, reoccurrence of cancer cells, and destruction of healthy cells. Consequently, scientific research has been focused over the years for the anticarcinogenic activities of plant-based extracts.

Zakaria et al. (2011) conducted a study on the usage of different leaf extracts (methanolic, aqueous, and chloroform) on the in vitro inhibition of different cell lines, namely, HeLa cell line, breast cancer cell line (MCF-7), myelogenous leukemia cell line (K-562), leukemia cell line (HL-60), human breast carcinoma (MDA-MB-231), colorectal adenocarcinoma cell line (HT-29), and embryonic fibroblast cell (3T3). All preparations proved safe as they showed no cytotoxicity on the normal fibroblast cells. The chloroform extracts were found to exert antiproliferative effects on the cancer cell lines of HL-60, K-562, HeLa, and MCF-7, while the methanolic and aqueous extracts inhibited K-562, HL-60, MCF-7, HT-29, and HeLa cells. No extract preparation affected the MDA-MB-231 cell lines.

Md Nasir et al. (2017) studied the anticarcinogenic activity of the methanolic extracts of *Muntingia calabura* leaves. Their study was directed at the chemopreventive activity of the extracts for the inhibition of azoxymethane (AOM)-initiated colon cancer in laboratory male Sprague-Dawley rats. An oral administration of the methanolic extracts (MEMC) at dosages of 500, 250, and 50 mg/kg MEMC was given to the rats and extensive histological studies followed. Their results showed an antioxidative activity of MEMC as signified by a decrease in the oxidant biomarker (malondialdehyde) with an increase in the antioxidant biomarkers in the colon tissue (glutathione, catalase, and superoxide dismutase). Furthermore, the anticarcinogenic strength of MEMC was reported by a reduction in the integral aberrant crypt formation. These remarkable results were linked to the possible mechanisms of reduction in the oxidative stress of the colon and increment in the quantities of antioxidants by the synergistic activity of multiple flavonoids such as pinocembrin, ferulic acid, gallic acid, and rutin.

Desrini and Purnamasari (2017) conducted an investigation involving metabolomic scrutiny and the evaluation of the induction of apoptosis and the growth inhibition of WiDr colorectal cancer cell line by the methanolic extract of *Muntingia calabura* L. leaves. Using thin-layer chromatography (TLC) and spectrophotometry, antioxidative secondary metabolites such as triterpenoids, saponins, flavonoids, and alkaloids were duly identified. The extract was found to instigate morphological alterations causing apoptosis in the cancer cell line, and an in vitro cytotoxic examination showed half maximal inhibitory concentration (IC50) values of 40.22 μg/mL and 39.21 μg/mL in a dose-dependent course against the cancer cells.

13.3.3 Peptic Ulcer

Peptic ulcers are breaks, holes, or sores that evolve in the segments of the digestive system that are associated with enzymes and stomach acids such as the interior lining of the stomach or the coverage lining of the duodenal part of small intestine. Common types include duodenal, stomach, and esophageal ulcers and are usually caused by factors such as nutritional deficiencies, smoking, stress, infections, and drug abuse.

Their pathogenesis however results from disequilibrium amongst the guarding components of the gastric mucosa such as bicarbonate secretion and mucus, adequate blood flow, antioxidative enzymes, sulfhydryl compounds, cellular regeneration, prostaglandin, and secretion of digestive factors like pepsin and acid (Hoogerwerf and Pasricha 2006).

Pharmaceutics have been developed for this condition, but besides their side effects, the affordability of such is a subject of concern since peptic ulcer affects patients of all income groups. Accordingly, the adoption of plants and plant-based materials for the management of peptic ulcers has been of interest over the years, and vegetative parts (especially its leaves) of *Muntingia calabura* have been efficiently adopted for this purpose. Furthermore, experimental studies have proven that regardless of the extraction solvent(s) employed, the antiulcer and gastroprotective effects of the extracts obtained from *Muntingia calabura* were imparted.

Balan et al. (2013) studied the potentiality of methanolic extracts of *Muntingia calabura* leaves for the management of ulcer in vivo. The extract was fractionated with distilled water, ethyl acetate, and petroleum ether and was orally administered to laboratory rats for 7 days, in dosages ranging from 100 to 500 mg/kg. Results obtained from their study showed that all extract fractions showed gastroprotective effects in the animals having ethanol-induced gastric ulcer with regard to attenuation of gastric lesion and with the fractions of ethyl acetate and petroleum proving their functionality in a dose-dependent trend. The aqueous fraction however was effective for 250 and 100 mg/kg but ineffective at 500 mg/kg.

Zakaria et al. (2014) conducted a similar study but with the gastric ulcer induction in the laboratory rats by ligation of the stomach pyrrole. The rats were orally administered with the methanolic extracts of *Muntingia calabura* leaves in doses of 100–500 mg/kg for 7 days. The gastroprotective effects of the extracts were measured on the basis of gastric juice parameters such as total acidity (mEq/l), free acidity (mEq/l), pH, and volume of gastric juice (mL). Their results showed that the 500 mg/kg dosage was superlative with the least values for all parameters, showing a reduction in gastric ulcer effects. Interestingly, their results also showed that the gastroprotective functionality did not follow a dose-dependent course with more positive results obtained for the 100 mg/kg in comparison with 250 mg/kg dosage.

Zakaria et al. (2015) examined the in vivo and in vitro gastroprotective effects of the chloroform extract of *Muntingia calabura* leaves. The results from their experimentation showed that the extracts were effective for gastroprotection possibly due to their activities in enhancing the defense of the gastric mucosa, anti-inflammatory actions, and antioxidative constituents.

13.3.4 Antipathogenicity

A pathogen is a biological and infectious entity (particularly microbial) with the natural predisposition to induce disease in a host. Common examples are bacteria, viruses, protozoa, and fungi with typical attack mechanisms of immunosuppression, expropriation of nutrients, multiplicative colonization, tissue invasion, and syntheses of toxins (Bhunia 2018). Contemporary pharmaceutics and associated medical sciences have formulated several products such as antibiotics and vaccines to combat the influence of pathogens. Likewise, the human body has its natural defensive responses to fighting pathogenic infections such as increased temperature, coughing, and sneezing and by the biochemical pathways of the immune system through the employment of antibodies (Zhang et al. 2018).

Plant materials have also shown formidable strengths against pathogenic infections. Extracts obtained from *Muntingia calabura* parts have shown antimicrobial effects against common pathogenic microorganisms. Buhian et al. (2016a, b) experimented on the antipathogenic activity of ethanoic extracts obtained from the stem and leaves of *M. calabura* with the disc diffusion assay methodology. Their results showed that all extracts were functional in inhibiting *Candida albicans*, *Bacillus subtilis*, *Escherichia coli*, *Salmonella typhimurium*, and *Pseudomonas aeruginosa*, though the inhibition against *E. coli* was found to be least and for three of the pathogens, namely, *P. aeruginosa*, *S. aureus*, and *C. albicans*, the minimum inhibitory concentration values showed the maximum inhibition.

Zakaria et al. (2010) also performed a study on the antimicrobial strength of multiple solvent extracts and solvent partitions of *Muntingia calabura* leaves. At a preparation proportion of 1:20 (w/v) for a time duration of 72 h, solvents including distilled water, methanol, and chloroform were distinctively used to obtain extracts from the leaves. Pathogens such as *Staphylococcus aureus* 25923, *Microsporum canis* ATCC 36299, *Candida albicans* 10231, *Pseudomonas aeruginosa* ATCC

27853, *Escherichia coli* 35218, and *S. aureus* 33591 were used to examine the antipathogenic activities of the extracts. The methanolic extract was reported as most effective against *S. aureus* ATCC 25923 with identical minimum bactericidal concentration (MBC) and minimum inhibitory concentration (MIC) values of 1250 μg/ml and also for *S. aureus* ATCC 33591 with similar MBC and MIC values. The extract was further partitioned separately with ethyl acetate, petroleum ether, and distilled water with the partition obtained from ethyl acetate found to possess MBC/MIC values of 313 and 156 μg/ml against *S. aureus* 33591 and *S. aureus* 25923, respectively.

Ravikumar and Garampalli (2013) macerated young twigs and flowers of *Muntingia calabura* with distilled water and used the filtered extracts as an antifungal agent against *Alternaria solani* suing the poison food technique. They reported an inhibition of 20.09% and a colony diameter of 6.6 $\pm$ 0.1 mm against the fungus.

13.4 Conclusion

M. calabura is one plant found in diverse countries of the world particularly due to its tolerance to various climatic and/or soil conditions. Several analyses regarding its qualitative nutrient composition have shown its richness in macro- and micronutrients. However, beyond its nutrient value lie its pharmacological and therapeutic health benefits. Several researches have shown that extracts obtained from vegetative parts of *M. calabura* possess one or more health benefits such as antidiabetic, antihypertensive, antioxidant, anticancer, and so on. The antioxidant potentials of extracts obtained from *M. calabura* have been qualitatively associated to its inherent phytonutrients. Various investigations conducted in vivo and in vitro have shown the formidable strength of these extracts in inhibiting oxidation and associated health disorders. However, there is a need for more scientific scrutiny on this subject for the maximal exploitation of the biological functionalities embedded in *M. calabura*.

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Black Current 14

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Abstract

Black currant is the main species of *Ribes* and is known for its versatile health benefits. It is also recognized for being a valuable source of polyphenols including vitamin C, anthocyanins, and flavonols and has antioxidant properties, with a potential to protect against various diseases like cancer, cardiovascular disorders, anti-inflammatory, and other degenerative risks. Black currants can be consumed either raw or cooked in the forms such as jams, jellies, and syrups or can be processed to juice. Apart from fruits, other anatomical parts of black currant are also rich sources of bioactive compounds. Seeds contain significant amounts of oil with high essential fatty acid contents and also contain significant amounts of antioxidants. The leaves have been reported to possess antimicrobial activity and can be used as a natural preservative in different food systems. Buds are utilized for the production of essential oil and aromatic volatile compounds that can be used as an aroma enhancer in perfume and cosmetic industries. Moreover, black currant contains flavonoids that have direct impact on human health. So, there is a need to analyze the function and structure of bioactive compounds present in

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black currant. Biological activity, bioavailability, and metabolism of polyphenols present in berries depend mostly on the hydroxyl groups, configuration, and its functional group substitution. Thus, this chapter highlights the biological aspect of black currant, its production, antioxidant properties of fruit and other anatomical parts, and the products prepared from black currant. This chapter also deals with the structural characteristics of flavonoids and their health-promoting compounds that have a beneficial role in human health.

Keywords

Black currant · Health benefits · Antioxidants · Polyphenols · Flavonoids

14.1 Introduction

Botanical Name: *Ribes nigrum*
Common Name: Black currant

Black currant (*Ribes nigrum*), also known as cassis, belongs to the *Ribes* genus and the family Grossulariaceae, is a small deciduous shrub, and grows 1–2 m tall. It is cultivated mostly in the temperate region of Central Europe, New Zealand, Russia, parts of Northern Asia, and Eastern Europe (Hummer and Barney 2002; Pfister and Sloan 2008). These berries are famous for their winter hardy, and their growing characteristics are adapted according to the temperate region. The best season for the fruits to perform well includes mild summers and cold winters. High temperature during mid summers induces greater risk of damage to fruits. During dormancy, insufficient chilling affects the phonological traits such as bud breaking, duration and time of flowering, and, during the time of harvest, the quality of fruit (Hedley et al. 2010). Black currant cultivation is negatively affected by the drought in summer and spring frost (Kahu et al. 2009). Warm weather conditions increase the biochemical compounds like soluble solid contents and accumulate less acid, and environmental stress has been shown to have more effect on fruit acids rather than the sugar content (Brennan 1996).

Black currant is a small berry fruit, spherical in shape, and blackish blue in color and grows in clusters, not loose. This plant is hermaphrodite, that is, it contains both male and female parts, making it a self-fertile plant by pollination due to bees. The plant has tasty juice and is sweet and aromatic and has edible seed-containing berries of 12 mm in diameter. The genus *Ribes* comprises of over 150 species (diploid) of shrubs containing both spiny and non-spiny (Brennan 1996). The safe (edible), fit to eat forms of fruit are black (*Ribes nigrum* L.), white (*R. sativum* Syme), and red currants (*R. rubrum*). These berries are a rich source of bioactive components, phytonutrients, and antioxidants, such as anthocyanins, vitamins (A, C, and E), essential fatty acids, very rare omega-6 fatty acid, polyphenols, GLA (gamma-linolenic acid), and other important constituents of phytochemicals (Bordonaba and Terry 2008; Brennan 2008). The most important anthocyanins present in

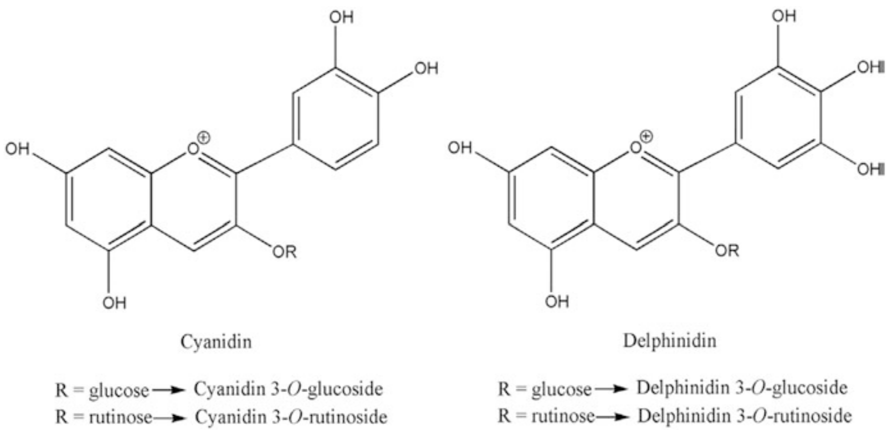


Fig. 14.1 Anthocyanins present in black currant. (Djordjevic et al. 2010)

black currants are delphinidin-3-rutinoside, cyanidin-3-glucoside, cyanidin-3-rutinoside, and delphinidin-3-glucoside (Fig. 14.1) (Lister et al. 2002; Brennan 2008; Bordonaba et al. 2010). In black currant, phenols are the major contributors of high antioxidant activities, but ascorbic acid is equally important (Lister et al. 2002).

Industrially, this fruit is widely used in food processing as it contains unsaturated fatty acids, flavonols, procyanidins, organic acids, polysaccharides, pectins, simple sugars, etc. (Brennan and Graham 2009; Tabart et al. 2007; Slimestad and Solheim 2002). In berries, the ratio of sugar and acids can act as an important factor for determining the quality and taste of fruit, especially when fruit is produced for fresh consumption (Bordonaba and Terry 2008). The vitamin C has been reported as high as over 50 times as in apples and 3–4 times as high as in oranges (Dale 2000). Apart from the fruit, other anatomical parts such as leaves, seeds, and buds can be utilized and are also considered to be rich sources of polyphenolic compounds. Buds and leaves have excellent application for the health and food industries, and, therefore, black currant can be used as a nutraceutical and functional food ingredient. The leaves of the plant are also used in the fabrication of dyes like yellow, and from seeds oil can be extracted, which is often used in cosmetics. The quality of black currant is determined by their nutritional profile, sensory properties, and chemical composition. The positive effects of currants help in curing of various diseases such as osteoporosis, cancer, hypertension, cardiovascular, etc. (Knekt et al. 1996; Seeram et al. 2003).

Black currants can be taken as raw or most commonly in the form of cooked sweet or savory dishes like jams, jellies, and syrups. Black currant has applications in the preparation of both alcoholic and fruit beverages. Mostly 80% of black currants are used for the production of juice, while remaining fruit is used in preserves, desserts, teas, liqueurs, wine, confectionary, yoghurt, and other dairy products. It is also used for the manufacturing of scented goods like fresheners, perfumes, and candles (Dale 2000; Hummer and Dale 2010). Leaves of the plant have extreme fragrance and thus can be used as excellent flavor enhancers in soups. The dried black currant leaves are also used for manufacturing of teas. Black currant can also be used as a traditional medicine for wound healing, stomach pain, and inflammation affecting the oral cavity. Dried black currant can be used as main ingredient in “pemmican” (mixture of dried meat and fat). In England, black currants were also known as squinancy berries as they were used to treat tonsillitis (quinsy). The seeds are a rich source of omega-6 fatty acid (type of gamma-linolenic acid) (Brennan 1990). Black currants are low in sodium and calories as compared with other fruits, but contain significant levels of potassium, calcium, iron, and vitamins including A, B1, B3, and E as shown in Table 14.1.

14.1.1 History

The word “currant” is taken from Corinth – the ancient city of Greek. These berries were grown as small dried grapes (Hederick 1925; Brennan 1996). Black currants, as a domesticated plant, have been cultivated for more than 400–500 years in Northern Europe. In Russia, black currants were grown since the eleventh century. The diversity of black currant extends from northern Scandinavia across Russia. In the twentieth century, breeders used wild germplasm for crosses like *R. pauciflorum* and *R. dikuscha* that resulted in the growth and development of locally adapted cultivars such as Brodtrop and Ojebynand‘PrimoskijCempion (Brennan 2008).

In 1611, black currants were imported to the United Kingdom from Holland by John Tradescant at the beginning of the seventeenth century, and by 1800 in the United Kingdom, these berries were cultivated in home gardens (Hederick 1925; Brennan 1996). The black currant was first recorded as herbal (Roach 1985) and used as ingredients in medical concoctions and tea (Barney and Hummer 2005). In the early stages of the eighteenth century, trade related to berries and first orchard were seen in Eastern Europe and Russia. Five cultivars of black currant were identified in 1826 by the Royal Horticultural Society: Wild Black, Black Grape, Russian Grape, Black Naples, and Common Black. Apart from these cultivars, by 1920, more than 26 additional cultivars of black currant were recognized (Hatton 1920). In 1920, Hatton classified the cultivars into four similar genotype groups: Goliath, Boskoop Giant, Baldwin, and French Black. From the late nineteenth century in the United Kingdom, the most essential cultivar was “Baldwin” (unknown origin). It is still grown today in some regions but on reduced scale, as its crosses led to the late flowering development. The cultivar of black currant is famous in the United Kingdom for their deep purple color, as it contains high level of anthocyanins and gives benefit to the environment like disease and pest resistance.

In the seventeenth century in the United States, black currant was introduced along with red currants (Barney and Hummer 2005). In the early 1900s, the production of berries was regressed in North America whereas it was higher in the European countries. The main cause for the regression of the manufacturing of black currant was white pine blister rust (rust disease) caused due to the fungus

Table 14.1 Proximate composition of raw black currants in comparison to other fruits of edible portion (per 100 g)

						Vitamins			
Fruits	Calories	Fat (g)	Protein (g)	Water (%)	Carbohydrate (g)	A	B1	B3	C
Black currant	63	0.41	1.4	81.96	15.38	230	0.05	0.3	181
Gooseberry	44	0.58	0.88	87.87	10.18	290	0.04	0.3	27.7
Red currant	56	0.2	1.4	83.95	13.8	120	0.04	0.1	41
Orange	40	0.3	0.3	82.3	15.5	250	0.10	0.5	71
Apple	59	0.36	0.19	83.93	15.25	90	0.017	0.077	5.7
Strawberry	30	0.37	0.61	91.57	7.02	27	0.02	0.230	56.7

Source: Vagiri (2012); Hummer and Barney (2002)

Cronartium ribicola JC Fisch. This infection developed in the early nineteenth century and the late eighteenth century. Around this time, the currants lost their popularity as farm crop as it caused a lot of damage to white pine trees; then the decision was made to eliminate currants. In 1966, the ban was lifted so as to make black currant cultivation viable again. Since then, various states removed the regulations while others still have ban in place. In Canada, during the 1930s and the 1940s, rust-resistant *Ribes* were developed by combining Cr gene from wild germplasm of *R. ussuriense* with cultivar of black currant and developed three cultivars: Crusader, Consort, and Coronet (Hunter 1955). In the past several decades, various rust-resistant varieties have been released like *Minaj smyriou* (Russian cultivar) and *Titania* (Swedish cultivar) (Barney and Hummer 2005).

During World War II, citrus fruits like fruits rich in vitamin C, oranges, etc., became very hard to import and cultivate in Europe; therefore, black currants were used exceptionally at that time as it contains high level of vitamin C. The production and cultivation of currants were encouraged also for the manufacturing of healthy and functional juice. From that time on, the cultivation of black currants was encouraged and the yield was also increased significantly due to its strong flavor and richness in polyphenols and essential nutrients.

14.1.2 Production (World and India)

Black currant berries are indigenous to Europe, Asia, Northern and Southern America, and Himalaya. In the year 2017, the production of blackberry in the United States was $31.1 million. Black currant is economically essential crop fruit having an annual turn of above 185,000 tonnes worldwide and 160,000 tonnes in Europe (Hedley et al. 2010). *Ribes* is commercially important fruit, as 99% of world's production comes from Europe. It could be seen from the production figures that Poland, Germany, and the United Kingdom account for over 80% of the total production. Poland is the main producer of *Ribes* followed by the United Kingdom. In the case of non-European countries, New Zealand is the largest producer, with Canada in second place and followed by the United States. In Sweden, black currant production approximately covers 400 ha, and there is still huge potential to enhance the cultivation due to soil conditions and favorable climatic conditions.

The production of black currants is increasing in the world (Table 14.2; FAO 2017), and since then, there are demands for cropping better cultivars.

14.1.3 Biological Aspect

Black currant is an aromatic deciduous shrub, temperate species, which was earlier considered in the family of Saxifragaceae, but now it is present in the Grossulariaceae family due to its morphology (floral) (Sinnott 1985; Cronquist 1981). *Ribes* is the only genus in the family that has 6–12 subgenera (Berger 1924; Keep 1963). Black currant is winter hardy with an optimal temperature of

Table 14.2 Highest currant-producing countries in the world

S. no.	Country	Production in tonnes
1.	Russian Federation	351,304
2.	Poland	128,808
3.	Ukraine	271,40
4.	United Kingdom	138,99
5.	Germany	124,70
6.	France	9750
7.	New Zealand	9092
8.	Hungary	3911
9.	Denmark	3305
10.	Austria	2963
11.	Azerbaijan	2505
12.	Finland	1888
13.	Netherlands	1795
14.	Uzbekistan	1786
15.	Czechia	1609
16.	Spain	900

Source: FAOSTAT Database Results (FAO 2017)

18–20 °C needed for growth and 15–25 °C temperature for photosynthesis. Temperature above 35 °C is unfavorable and thus causes leaf fall. Black currant prefers soil with a pH range of 6–7, well drained, moisture retention, deep sandy soils, and damp fertile soils or fertile loams. The crop on the maturity starts giving the fruit in 3–4 years (Vagiri 2012). Shoots are firm, long, straight, brown in color, and thick at the base (Wassenaar and Hofman 1966). Buds are reddish or yellowish in color, short, slender, thick, and tapering in shape. As the winter months progress, the bud color becomes reddish in color. The leaves of *Ribes* are perfumed and pale green in color and have a lobed shape for easy identification. Leaves also contain many aromatic glands on the lower part of surface of leaf. These leaves produce different biochemicals for plant growth and development by the process of photosynthesis and subsequent metabolic pathways. The flower cluster hang down and bear almost 10 and 12 flowers per raceme, having reddish or brownish bell-like shape. The petals are very small and hypanthium is flat. *Ribes* leaves are an excellent source of chemical compounds known as terpenoids and phenolics. In 1988, Marriot found 44 chemicals in the leaf oil alone. If the leaves are severely damaged or removed, new shoots are developed by breaking down the buds and then spoiled leaves are replaced by new leaf.

Black currants have 8 chromosomal number, similar to *Ribes* species ($x = 8$) (Zielinski 1953), and all the species and cultivars are diploid ($2n = 2x = 16$) (Brennan 1996). The chromosomes undergo both mitotic and meiotic processes and are having a diameter of 1.5–2.5 mm (Zielinski 1953).

Black currant species and cultivars are self-pollinated, insect pollinated, or cross-pollinated in achieving average yields (Denisow 2003; Brennan 2008). Insects like bumble bees are very essential for the pollination. The bloom of flowering is mainly dependent on the environmental conditions like temperature to which the plant is exposed and type of cultivar. These berries are very sensitive to low temperatures. Therefore, supercooling should be lowered such that more cultivars can withstand at a minimum temperature of −5 °C (Brennan 2008). Thus, new cultivars are being produced that are resistant to very low temperatures. Moreover, mild summers are also important for intense sunlight and high temperatures that may enhance the foliar damage (Šavikin et al. 2013; Vagiri 2012). Flowering mostly takes place in the month of May, up to 3–4 weeks as per the above two criteria. Black currants grow best on deep organic soils with pH ranging between 5.3 and 7.0 (Hummer and Dale 2010) and with good aeration and water retention capacity.

In most of the countries, black currant breeding is done by collecting the berries as they mature. Fruits are then kept at a temperature of 4 °C and with the help of blender seeds are extracted. These seeds are then dried by using filter paper and thereafter put in compost. The compost was then wrapped in a film of moist vermiculite, followed by stratification in dark for 12 weeks at 2 °C. Later, germination of seeds takes place in greenhouse. This germination gets completed within 2–3 weeks. In glasshouse, the seedlings are mostly raised and then sowed in the field when soil is crumbly and dry (October to March). During this period, the roots of plant are not hindered once they start growing. After planting, pruning is done in the first year for strong growth and development. In the second year, no pruning is needed and almost 0.202 tonnes per hectare is produced, followed by high yield of crop in the next year (Blackcurrant Foundation 2011).

14.2 Antioxidant Properties

14.2.1 Fruit

Black currant berries are known for their natural high contents of essential nutritional components and health benefits since long. At first the fruit was used for medicinal purposes, but nowadays it is consumed as food item (Hummer and Barney 2002). The berries are recognized due to their rich organoleptic properties like flavor, intense color, and unique taste. Nowadays, the focus of research has shifted to its health benefits, quality and nutritional aspects, and different cultivation techniques in various geographical locations throughout the year. In comparison to other fruits, black currants are still regarded as one of the best fruits in terms of their polyphenol content, being highest in over 143 other fruits and vegetables (Karjalainen et al. 2008). Polyphenols, especially phenolic acid derivates, anthocyanins, flavonols, condensed tannins (proanthocyanidins), flavan-3-ols (catechins), and hydrolyzable tannins (ellagitannins and gallotannins), are higher in black currant fruit in comparison to other berry fruits like gooseberry, strawberry, red currant, raspberry, and white currant (Mattila et al. 2011; Karjalainen et al. 2009). Thus, black currants were regarded as a cost-effective and profitable fruit to be utilized as healthy food constituent (Macheix et al. 1990; Lister et al. 2002; McDougall et al. 2005; Anttonen and Karjalainen 2006).

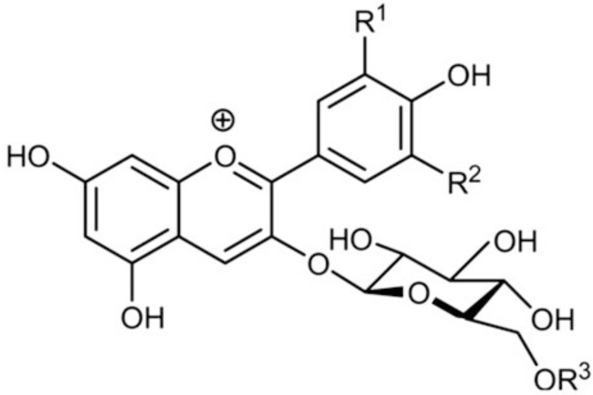


Fig. 14.2 Structure of main anthocyanins present in black currant

Black currants have fourfold greater anthocyanins than other fruits (Moyer et al. 2002; Kampuss and Strautina 2004). Anthocyanins are responsible for the color pigmentation in fruits and vegetables like in berries for red, black, blue, and purple colors and currants like blueberries, red, black currants, strawberries, raspberries, and vegetables such as red apples, blood orange, black grapes, and purple cabbage (Mazza and Miniati 1993). In black currant berries, 73% of antioxidant capacity was accounted by anthocyanins while ascorbic acid contributed 18%. Out of 73% of anthocyanin antioxidant activity, 47% was contributed from delphinidins and 23% from cyanidins (Borges et al. 2010). Flavonol content of black currants is mainly due to the presence of myricetin and quercetin, with less content of kaempferol (Mikkonen et al. 2001). Anthocyanins have four major groups of pigments in black currant like delphinidin-3-O-rutinoside, cyanidin-3-O-rutinoside, delphinidin-3-O-glucoside, and cyanidin-3-O-glucoside (Fig. 14.2) (Mazza 2000; Anttonen and Karjalainen 2006). At 5′ position cyanidin possesses a hydrogen atom, while at 5′ position delphinidin possesses a hydroxyl group (Nielsen et al. 2003). Further study showed that the composition of anthocyanin in black currants has 13 anthocyanin structures in its extract like pelargonidin-3-O-glucoside and pelargonidin-3-O-rutinoside, peonidin-3-O-rutinoside, peonidin-3-O-glucoside, petunidin-3-O-glucoside, petunidin-3-O-rutinoside, cyanidin-3-O-arabinoside and cyanidin-3-O-sophoroside, and delphinidin-3-O-sophoroside, malvidin-3-O-glucoside and malvidin-3-O-rutinoside, delphinidin-3-O-(60-coumaroylglucoside), and cyanidin-3-O-(60-coumaroylglucoside) (Fig. 14.2); these structures were identified by HPLC-DAD-MS technique (Slimestad and Solheim 2002).

The biological value of berries depends on their nutritive and non-nutritive composition. In black currants, the mineral nutrients are especially rich sources of calcium, magnesium, iron, zinc, and potassium (Magazin et al. 2011). Compared to other fruits such as cranberries, oranges, blueberries, and grapes, black currant berries have highest content of minerals. The ascorbic acid content of black currants is three times as high as oranges, the antioxidant level is high than for blueberries and potassium content similar to the bananas (USDAARS-National Nutrient Database for Standard Reference Release 28).

Black currant berries are known for their health-promoting benefits due to the presence of different bioactive compounds. Black current berries are suitable to be consumed in fresh or frozen form or can be processed into different forms like concentrates, candies, jams, flavored water, jellies, dessert toppings, fillings on pies, ice creams, or as an ingredient for functional foods. Their isolated compounds or extracts can also be used as healthy ingredients in several supplements. In different countries around the world, these berry fruits (black currants) are used for the manufacturing of liquors such as crème de cassis or liqueur de cassis and for the conversion of white wine to rose (Brennan 1996). In Sweden, few varieties of black currant are used for the production of strong alcoholic drinks (40% approx) like Absolut Vodka, svartavinbarsbranvin, and black currant schnapps.

14.2.2 Juices

The shelf life of black currant berries is typically limited; therefore, processing and storage have been extensively studied to determine the effect on quality parameters of berries, especially freezing (Zhao 2007). Berry fruits are mostly used in the form of juice that maintains the antioxidant activity of berry as reported by Sandell et al. (2009). The juice produced from the black currant berries has a unique and distinct flavor. It has been reported by Varming et al. (2004) that this unique flavor and aroma comprises of more than 120 volatile aroma constituents like esters, alcohols, and terpenes. Processing of juice like particle size and mulching has a direct effect on the phenolic content of black currant, particularly anthocyanins in juice (Sojka and Krol 2009). For the highest phenolic content of juice, the size of parts of currant should be from 2 to 5 mm. Processing of black currant berries to juice leads to lowering of phenolic content even up to 80% (Hakkinen et al. 2000). The reduction of total phenols during processing is due to high levels of pectin in the epidermis of cell wall that could avoid extractions of such components from the berry (Hilz 2007). This reduction of phenols could be prevented by giving enzymatic treatment, which enhances the phenolic content in the processing of juice (Buchert et al. 2005) such that adding up of apple juice to berry juice (Oszmiański and Wojdyło 2009) could increase the antioxidant activity and total phenolic content from 40% to 100%. The black currant juice contains substances that have macrophage-stimulating activity such as anthocyanins, proanthocyanidins, and polysaccharide-rich substance. Juices from black currant have highest phenols and radical scavenging capacity as compared to other berry fruit juices (Konic-Ristic et al. 2011). Red currant juice contains 133 mg GAE/100 ml of total phenolic content, while as for black currant it ranged up to 260 mg GAE/100 ml juice. Moreover, during freezing the bioactive compounds were reduced. The phenolic content of black currant juice decreased by 50% when stored at 4 °C for 6 months while keeping in freezer resulted in a loss of less than 20% of total phenolic content (Hakkinen et al. 2000). Another researcher showed that low sugar jam prepared from black currant, without use of any additives, and processed at a temperature of 92 °C and stored at 8 °C still contained antioxidants and vitamins at high levels even after 12 months of storage (Viberg et al. 1997) and the β-carotene were also found to be stable during this period. According to Alonso Gonzalez et al. (2010), black currant berries could be utilized as a substrate for alcoholic beverages made from the process of fermentation that are done by the fruit distillation method, fermented formerly by *Saccharomyces cerevisiae*. In black currant distillate, the amount of volatile compounds (122.1 g/hL absolute alcohol) was lesser than that of its lower limit (200 g/hL absolute alcohol) as per the European Council (Regulation 110/2008), and thus there is no risk to human health.

14.2.3 Seed

Currant seeds are by-products of fruit processing and are known to be a valuable source of oil. Black currant seed oil contains high amounts of essential fatty acids such as stearidonic acids, omega-6, omega-2 fatty acid, γ-linolenic, and R-linolenic with significant levels of tocopherols and phytosterols (Bakowska-Barczak et al. 2009). The oil contents in the seeds of black currant range from 18.3% to 27.6% (Šavikin et al. 2013). Recent studies reported that black currant seed contains a significant number of antioxidants (Parry et al. 2006) and the profiles of phenolic acids, anthocyanins, and flavonols are identical to that present in the berries (Lu and Foo 2003). According to Lu et al. (2002), two novel constituents, nigrumin-5-p-coumarate and nigrumin-5-ferulate, together with six known flavonoids were isolated successfully from the residues of black currant seed after supercritical CO_2 extraction. The Canadian black currant seed oil is a good source of tocopherols (1143 mg/100 g of oil) and phytosterols (6452 mg/100 g of oil) and is also rich in essential fatty acids. In seed residues, the two main phenolic compounds were quercetin-3-glucoside and p-coumaric acid. The maximum antioxidant activity of seed residues (average DPPH value of 1.2 mM/100 g and ABTS value of 1.5 mM/100 g) was interlinked with high level of flavonols and phenolic compounds.

14.2.4 Peel

Black currant peel is tougher and transparent in color. It is enriched with polyphenols, especially anthocyanins, that end up as a residue instead of juice during processing. Blackberry peel is a potent antioxidant that vivifies skin tissue and also contains high levels of vitamin C that brightens up the complexion and repairs the damaged skin.

14.2.5 Wastes

The other anatomical parts of black currant like buds and leaves are also excellent sources of flavonols and phenolic compounds (Tabart et al. 2006, 2007). Black currant leaves when dried and reduced to powder by mechanical means like grinding are used to mix it with extracts of buds such as glycerin. Those macerated in glycerin were used as an ingredient for various industries like cosmetic, health, medicine, and food. The intense colors and pleasing flavors imparted by leaves and buds are comparable to that of the berry fruits (Dvaranauskaite et al. 2008; Tabart et al. 2006, 2011).

Recent studies have shown that leaves of black currant contain significant amounts of polyphenols. It contains almost five times higher antioxidant ability than that in the fruit (Tabart et al. 2006). Leaves have flavonoid derivates like quercetin, kaempferol, and phenolic acids (Raudsepp et al. 2010). Another study also showed that black currant leaves have antimicrobial activity similar to that of some essential oils (Stevi et al. 2010). Leaves have been reported to be used as preserves or flavor in tea and also used in soups. Black currant leaves are infused in sweetened vodka resulting in a deep yellowish-green drink with astringent taste and sharp flavor.

Black currant buds are a potential source of biologically active compounds. Buds are utilized for the production of essential oils and aromatic volatile compounds for application as aroma enhancer in perfume and cosmetic industries (Dvaranauskaite et al. 2009; Castillo del Ruiz and Dobson 2002; Piry et al. 1995). Black currant buds distilled an essential oil known as "Nirbine" that has an application in the food and alcohol industries. Essential oil of *Ribes nigrum* exhibited strong antimicrobial activity against certain bacteria like *Acinetobacter baumannii*, *E. coli*, *P. aeruginosa*, and *Staphylococcus aureus* (Oprea et al. 2008). The composition of polyphenolic compounds in buds has been reported by Vagiri et al. (2012). According to this report, the variations in these compounds during growth and development are due to the different stages of seasons. It was also reported that in the month of March, enlarged buds were collected and had a maximum level of phenols with rutin, epicatechins, and kaempferols while the chlorogenic acid level was minimum throughout the season.

14.3 Antioxidant Properties of Products Prepared from Black currant

Raikos et al. (2018) studied the antioxidant characteristics of a yoghurt beverage enriched with black currant pomace and salal berries (*Gaultheria shallon*) during storage. In this study, an aqueous extract of berry skin and fruits (dried) was taken as a phenolic compound source to fortify the yoghurt beverage. The anthocyanin, antioxidant activity, and total phenolic content of the fortified yoghurt were compared with plain yoghurt during storage at a temperature of 4 °C for a period of 4 weeks. It was found that the fortified yoghurt beverage with salal berries had high phenolic, antioxidant, and anthocyanin contents as compared to black currant pomace. Thus, findings of this investigation indicate that both salal berry and black currant pomace can be used to enhance the antioxidant activity of fortified yoghurt beverage.

Oszmiański and Wojdyło (2009) evaluated the effect of apple pulp blended with black currant mash on the color, antioxidant property, and phenolic content of juice production during storage. Five different samples were processed: the Shampion and Idared: two different cultivars of apple juices without and with 20% of black currant juice and pulp were then stored at a temperature of 30 °C and 4 °C for a period of 6 months. Juices processed from two cultivars of apples showed lower ascorbic acid content, while a higher amount of ascorbic acid was detected in juices prepared from black currant. The addition of black currant pulp (20%) and black currant fruits before crushing of apple had significantly ($p \leq 0.05$) different effect on phenolic content in comparison with control samples, juices prepared from 80% of apples of cultivar Idared blended with black currant berries (20%) had four times higher flavonol concentration in juices. Black currant juice blended with apple pulp was richer in ABTS, DPPH, FRAP, and hydroxycinnamic acid as compared to juices prepared from apples only. The maximum amount of antioxidant activity was observed in the samples of black currant juices due to the high influence of ascorbic acid and anthocyanin contents. The color of apple juice showed a slight degradation at 4 °C for 6 months, while a maximum degradation was seen in the samples stored at 30 °C with respect to time. During storage (30 °C), it was also found that degradation of antioxidant activity, color, and all phenolic compounds takes place.

The effect of black currant and *Aronia* pomace to replace fat or sugar, flour in sponge cakes were assessed by Quiles et al. (2018). Highest viscosity was showed by the batters which were replaced by sugar. Moreover, batters replaced with flour led to lowest viscosity and thus produce softer cakes with less and larger sized air cells. Replacement of sugar showed higher degree of hardness and a greater number of small air cells. Generally, it was found that replacement of fat in comparison to sugar and flour replacement showed an increase in structural properties and crumb texture. Thus, different replacements in sponge cakes were well accepted by the mass consumers.

Effects of pasteurization and different juice matrix on the stability of total anthocyanins of blackberry during storage were examined by Dobson et al. (2016). Black currant juice and mixtures with persimmon, peach, and apple juices were taken at two different temperatures of 4 °C and 20 °C. It was shown that in juices at both temperatures, total phenolic content decreased. The decrease of total anthocyanins in unpasteurized and pasteurized juices lies according to the type of juice and the temperature at which the juices are stored. At 4 °C storage temperature, anthocyanins lowered in all juices as per pseudo-first-order kinetics, and there were very less differences between unpasteurized and pasteurized juices at this temperature. Moreover, at 20 °C storage temperature, both the unpasteurized and pasteurized juices of black currant and other pasteurized mixed juices followed the same first-order kinetics, but the unpasteurized mixed juice follows the different pattern; first it declined at a rapid pace and then slowed down. Thus, the effect of black currant added with mixed juices shows a decline in anthocyanins at different temperatures.

Punbusayakul (2018) aimed to evaluate the antioxidant activity and bioactive compounds of wines from several cultivars of currant like black currant, white currant, and red currant. These berry fruits were collected in Modrice, Czech

Republic, from a fruit nursery in July 2015 and then kept in a freezer at a temperature of -18 °C for further analysis. The black currant whole fruit was used directly for preparation of wine, whereas in the case of red and white currants, only juice was used for making wine. Total soluble solids (TSS) and titratable acidity (TA) of juice were adjusted, and then the juices were transferred to bottles for fermentation. After 12 days of fermentation, the result revealed that the wine prepared from black currant had maximum TSS followed by white and red currant wine. It was also found among all black currant exhibited highest TPC, DPPH, FRAP, and total monomeric anthocyanin (TMA) assay.

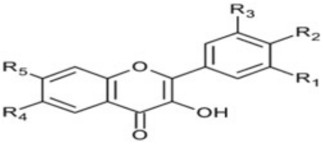
Bakowska-Barczak et al. (2009) reported that the residues left after the pressing of juice are a rich source of bioactive compounds with strong antioxidant property. In black currant cultivar, the total phenolic content present in its residues ranged from 160 to 230 mg GAE/100 g, with the maximum amount present in the variety Ben Sarek. Another study showed that residues after juice pressing contain 7–10 times higher total anthocyanins, total phenols, and antioxidant activity than in the edible part of berry itself (Kapasakalidis et al. 2006). Thus, this literature supports the claim that the maximum amount of phenolic compounds is present in the skin of fruit.

Tahvonen et al. (1998) evaluated breakfast cereals prepared from extrusion cooking using black currant seed. Black currant juice was produced by press residue, which was used for the development of highly nutritious breakfast cereal prepared by using an extrusion cooking at high temperature. Then the crushed seeds were mixed with milled residual fraction to have significant amounts of dietary fibers, minerals, and essential fatty acids. The highest useful quantity of this ingredient, almost 30% was mixed with 30% of oat bran and oat flour, 7.5% sugar, 30% potato starch, 1.5% extract of malt, and 1% salt. Thus, during the process of extrusion, the unsaturated fatty acids were not lost in significant amounts and the products also contained significant amounts of Ca (1.9 g/kg), Fe (59 mg/kg), and Mg (1 g/kg) and about 20% of total dietary fiber.

Additionally, black currants are extensively used and consumed across the world either in fresh or frozen form or in other forms like juices, in preparation of jams, jellies, preserves (Zhao 2007), desserts, teas, and other dairy products. All these products have high antioxidant properties, and thus blackberry and their extracts or isolated compounds can act as an active ingredient or can also be used as bioactives for various functional foods or in different dietary supplements (Sandell et al. 2009).

14.4 Characterization of the Chemical Compound(s) Responsible for Antioxidant Properties and the Pathways Involved in the Biological Activities

Phenolic compounds possess several biochemical features, but the excellent property described of almost every bioactive compound is their capacity to act as antioxidants. Phenolic compounds are reported to have positive functions against microbial attacks and can act as bioactive components (Mikkonen et al. 2001). These



Compound	R_1	R_2	R_3	R_4	R_5
Myrecetin	OH	OH	OH	OH	OH
Quercetin	OH	OH	H	OH	OH
Isorhamnetin	OCH_3	OH	H	OH	OH
Kaempferol	H	OH	H	OH	OH

Fig. 14.3 Structure of major flavonols present in black currant

compounds also possess health benefits like protection against cardiovascular diseases and different cancers (Karjalainen et al. 2009; Scalbert et al. 2005; Shahidi and Naczk 1995). The antioxidant capacity of flavonoids depends mostly on the functional group arrangement around the nuclear structure. The polyphenolic compounds are divided into distinct groups as per the phenol ring number and to the functional class linking with these rings. Black currant berries are known to possess a broad range of phenolic compounds like tannins, flavonoids, lignans, phenolic acids, and stilbenes (Paredes-López et al. 2010). Black currant berries have a wide range of bioactive compounds that contribute to their oxidative stability, bitterness, flavor, astringency, and color of their products. The substitution, configuration, and presence of hydroxyl groups, all the three factors influence the mechanism of antioxidant like ability of chelation of metal ion and radical scavenger activity (Pandey et al. 2012). The hydroxyl configuration of B ring is the most important for scavenging of ROS and RSN as it gives an electron and hydrogen to peroxyl, hydroxyl, and radicals of peroxynitrite to stabilize them and thus giving rise to a stable flavonoid radical (Cao et al. 1997).

Black currant berries possess large amounts of polyphenols when compared to other fruit berries like raspberry and strawberry. Flavonols are a group of compounds which contain derivates of phenolic acids like hydroxybenzoic acid and hydroxycinnamic acids and anthocyanins. The principal components of flavonols present in black currants are glycosides of myricetin, kaempferol, quercetin, and isorhamnetin (Fig. 14.3) as well as proanthocyanidins that makes it excellent target for healthy and functional food sector (Mattila et al. 2011; Karjalainen et al. 2009). Several researchers reported that:

1. Inhibition of enzyme can suppress the formation of ROS by chelating trace elements concerned in free radical generation.
2. Flavonoids, especially quercetin and naringenin, and its derivates from many plants like grapes, strawberry, green tea, cocoa, black currant, and citrus slow down the formation of ROS (reactive oxygen species) induced by β-amyloid protein and thus decrease the oxidative stress induced by neuronal cell membrane (Ramassamy 2006).
3. Protection or upregulation of antioxidant (Halliwell and Gutteridge 1998; Mishra et al. 2013a, b).

Oxidative stress is a common consequence of lipid peroxidation. Lipids are protected against oxidative damage by flavonoids (Kumar et al. 2013; Kumar and Pandey 2012). ROS formation is enhanced by free metal ions by reduction of hydrogen peroxide with the production of highly reactive hydroxyl radical. Flavonoids are thermodynamically stable due to their lower redox potentials and are able to decrease highly oxidizing free radicals like alkoxyl, hydroxyl, and peroxyl radicals by donation of hydrogen atom. Flavonoids also inhibit the generation of free radicals due to their ability to chelate metal ions such as copper and iron (Mishra et al. 2013a, b). Berries such as blueberries, bilberries, and black currants are a rich source of flavonols, particularly myricetin and quercetin (Borges et al. 2010; Maatta-Riihinen et al. 2004). In black currants, quercetin is known for its iron-stabilizing and iron-chelating properties. In black currant other than kaempferol, myricetin, and quercetin, other components like luteolin and naringenin derivates could also be identified.

According to the research and literature available, there are more than 110 different fruits whose chemical composition varies according to their different genotypes. Out of all the berries such as blueberries, blackberries, raspberries, etc., black currant had the highest average content of total phenols and total and individual anthocyanins and flavonols (Moyer et al. 2002). Lugasia et al. (2011) analyzed the total phenolic content in different varieties of black currant and found that it lies in between 229 and 871 mg GAE/100 g fresh weight of fruit. Among all different tested varieties, Tsema contains highest content of phenols followed by Ben Lomond and Tenah. Benvenuti et al. (2004) found that black currant contains 530–888 mg GAE/100 g of total phenolic content, whereas Giongo et al. (2008) evaluated that these values are in between 312 and 845 mg GAE/100 g of fresh fruit. Thus, in both studies, Tsema variety contains the highest number of phenolic compounds. The evaluation of free radical scavenging activity, DPPH, FRAP, and ABTS was done by high-performance liquid chromatography methods. This method can also be used for screening of flavonoid, flavan-3-ols, anthocyanin, hydroxycinnamic acid, and ellagic acid. It was found that black currant had highest scavenging activity than strawberries, red currants, raspberries, and plums (Bermudez-Soto and Tomas-Barberan 2004). The berry fruit of the genus *Ribes* is recognized to be an excellent source of anthocyanins and total phenolic content in several countries (Slimestad and Solheim 2002; Rubinskiene et al. 2005; Horbowicz et al. 2008); breeding programs were also aimed to enhance the nutritional value of berry.

14.5 Health Benefits

Black currants are excellent sources of phytonutrients, vitamins, antioxidants, minerals, flavonols, and essential fatty acids. Some of the health benefits related to black currant berries are:

- These berries are rich in vitamin C, a powerful antioxidant (Moyer et al. 2002), and are involved in the synthesis of proteins that are essential for the human body to produce certain neurotransmitters and collagens.
- Ascorbic acid plays an essential role in the metabolism of cellular features such as expansion of cells, photo protection, loosening of cell, control of cell cycle, stress perception, and response to plant pathogens (Hancock and Viola 2005).
- Blackberries contain high amounts of antioxidants like anthocyanins. These antioxidants help in fighting against the adverse effects of free radicals in the human body. Free radicals can damage the cells present in the body and also deteriorate the health conditions such as heart disease and cancer. Thus, the body utilizes antioxidants to minimize cell damage as well as chronic illnesses (Soobrattee et al. 2005).
- Black currant contains a large number of flavonols with high amounts of myricetin and quercetin. Both of these have application to possess protective effect against neurons.
- In black currant, isorhamnetin was recently found to have neuroprotective effect (Anttonen and Karjalainen 2006).
- Quercetin and isorhamnetin also reduce the risk of blood pressure and improve the flow of blood effectively in order to prevent it from development of vascular-type dementia (Karjalainen et al. 2009).
- Anthocyanins present in the black currant slow down the activity of enzymes cyclooxygenase 1 and 2 in the body and thus reduce effects of arthritis and inflammation in the human body.
- Fruit juices of black currant contain anthocyanins, proanthocyanidins, and polysaccharide-rich substance known as cassis polysaccharide (CAPS), which has macrophage-stimulating activity (Takata et al. 2005). CAPS has been reported to have a negative effect against tumor cells.
- Berries are also a good source of potassium and are known to possess potassium twice than the amount present in bananas.
- The extracts of anthocyanins have applications as antimicrobial, anticarcinogenic, antioxidant, antifungal, and antivirus. These extracts help in maintaining neuroprotective effect, enhancing immunity, and maintaining eye and vision (Han et al. 2007; Ramos 2008).
- Black currant is also helpful in treating other types of diseases due to bacterial infections like whooping cough.
- Black currant berries reduce the blood pressure and aggregation of platelet and have an optimistic impact on the metabolism of cholesterol (Konic-Ristic et al. 2011; Karjalainen et al. 2009).
- Blackberries are a rich source of vitamin K, which is essential for blood clotting and proper wound healing.
- Leaves of black currant have diuretic property. Consumption of tea prepared from dried leaves of black currant provides relief against diarrhea, coughs, bleeding gums, and urinary problems.
- Black currant oil is effective against a type of bacteria, *H. pylori*, that causes ulcers in stomach, nausea, and abdominal pain.

- The compounds present in black currants help in preventing glaucoma by reducing the levels of endothelin-1 (hormone). Glaucoma is an eye disease that causes blurredness and may lead to permanent blindness.
- Black currants are well suited for the treatment of uric acid stone diseases as it has an alkalizing effect. By having these berries, it not only increases the pH of urine but also excretes the critic acid from the body.
- Black currant juice is used to treat sore throat and cough.
- Researchers showed that black currant helps in killing viruses that cause both genital and oral herpes.
- Black currant bud oil has shown antimicrobial activity against bacteria and thus can be used for the treatment of infectious diseases (Opera et al. 2008).

14.6 Conclusion

Black currants are the main species of *Ribes*, widely known across the world for its production. It is recognized as an active constituent or ingredient of functional foods. Black currant is winter hardy with an optimal temperature of 18–20 °C needed for growth and 15–25 °C temperature for photosynthesis. Besides the biological aspects, other factors such as temperature, humidity, pH, light, agricultural practices, and extraction method significantly influence the phenolic content in currants. Berry fruits are mostly used in the form of juice that maintains the antioxidant activity of berry. The juice produced from the black currant berries has a unique and distinct flavor. It has unique flavor and aroma that comprises of more than 120 volatile aroma constituents like esters, alcohols, and terpenes. Additionally, currant seed oil contains high amounts of essential fatty acids, namely, stearidonic acids, omega-6, omega-2 fatty acid, γ-linolenic, and R-linolenic, with significant levels of tocopherols and phytosterols. Currant peel, a by-product during processing of juice, also contains polyphenols. Buds are utilized for the production of essential oil. Moreover, leaves of black currant contain a number of polyphenols and also have over five times higher antioxidant activity than that in the fruit. Additionally, the sugars and organic acids are the foremost groups of primary metabolites present in the currants. Secondary metabolites comprise of the most important group of anthocyanins present in black currants like delphinidin-3-rutinoside, cyanidin-3-glucoside, cyanidin-3-rutinoside, and delphinidin-3-glucoside. In black currant, phenols are the major contributors of high antioxidant activity, but ascorbic acid is equally important. Most importantly, currants have numerous biological activities that have shown a positive impact between the consumption of currant and health.

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15 Pomegranate

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Abstract

Pomegranate is a pome fruit that is cultivated throughout the world with various varieties. The most common varieties that are cultivated in India are *Ganesh* and *Bhagwa*. The fruit contains around 50–52% arils and 48–50% peel, pith, and carpellary membrane. Each part of the fruit contains various phytochemicals, viz. ellagitannin, gallotannins, ellagic acid, catechins, and anthocyanins. Pomegranate juice has various anthocyanins and antioxidative properties. Its seed can be used for the production of *anardana* and it contains fatty acids. Nowadays, the peel is utilized for production of various nutraceuticals using various extraction techniques. Ellagitannin extracted from peel has antioxidative and antibacterial activities against various pathogens. Ellagitannin can be used in supplementing sherbet for increasing its antioxidant properties. Bioactive components from pomegranate can control coronary heart disease and cancer and perform anti-inflammatory activities.

Keywords

Pomegranate · Phytochemicals · Ellagitannin · Ellagic acid · Antioxidant properties · Anti-inflammatory

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15.1 Introduction

15.1.1 Botanical Name and Common Name

Botanical name of Pomegranate is *Punica granatum* L., which belongs to *Punicaceae* family. Pomegranate name is derived from "Pomuni granatum," in which *Pomum* means apple and *granatus* means grainy, which is also considered as "seeded apple" (Da Silva et al. 2013; Pande and Akoh 2016). Pomegranate is known by different names worldwide, and few vernacular names of pomegranate have been shown in Table 15.1. Pomegranate (*Punica granatum*) is an important fruit having medium size, soft seeds, and reddish to dark-red flesh with sweet juice. The edible part of fruit is the "aril," which is a juicy outgrowth of pomegranate seed and it gives delicious juice.

The sour aril, when dried along with the seed, gives the "*anardana,*" which is generally used as a condiment. The fresh and fleshy kernels are being used for garnishing the dessert and salads (Al-Maiman and Ahmad 2002). Fruits of pomegranate are highly consumed in fresh form (as juice) and after that in preparation of jam, jellies, wine, flavoring, and coloring agent. In recent years worldwide demand of pomegranate juice (PJ) has increased significantly (Zhou et al. 2011). Seed, peel, and membrane part of pomegranate fruits are generally considered as waste material after juice extraction. It has been published that pomegranate juice and pomegranate peel extracts having potent biological properties due to the presence of polyphenolic compounds that are commonly known as ellagitannins (ETs). ETs present in pomegranate peel may serve as a preventive agent to control the cattle diseases and may also produce healthy meat products, when feeding through cattle feed (Shabtay et al. 2008). Pomegranate peel has been considered a very rich source of ellagitannins, for example, gallic acid (GA), ellagic acid (EA), punicalagin (PU), punicalin, and glycosides of ellagic acid (Gil et al. 2000; Cerda et al. 2003; Lu and Yuan 2008). Among these compounds, punicalagin has been identified as a major antioxidant with regard to health in human beings (Lin et al. 2001; Tzulker et al. 2007). ETs present in pomegranate have been identified as active compounds responsible for anticancer activities, protecting from oxidation of low-density lipoprotein and

Table 15.1 Vernacular name of pomegranate (Morton 1987)

Indian language	Vernacular name	International language	Vernacular name
Hindi and Punjabi	Anar	Chinese	Shiliu
Gujrati	Dadam	French	Grenade
Bengali	Dalim	German	Granatapfel
Oriya	Dalimba	Japanese	Zakuro
Sanskrit	Darimba	Italian	Melogranate
Kannada	Dalimbe	Russian	Granatnik
Malayalam	Matalam	Spanish	Granada
Tamil	Madulam	Swedish	Granatäpple
Telugu	Dhanimmapandu	Romanian	Rodie

cholesterols in vivo (Seeram et al. 2004). ETs extracted from pomegranate peel have been investigated for its potential uses as a bio-preservative in foods and as nutraceutical agents for the development of therapeutic food products.

There are many types of pomegranates like the double flowering, ornamental type, and a white flowered type (poor fruit quality) and are cultivated in India. They have the sugar content between 12 and 16% and they contain a considerable amount of tannins, polysaccharides, vitamins, and minerals (Al-Maiman and Ahmad 2002). Mahajan et al. (1992) have reported the richness of vitamin C and minerals, for example, calcium (Ca), zinc (Zn), manganese (Mn), and its application in production of various digestive medicines. Legua et al. (2012) have suggested that the genotype factor of pomegranate variety should be taken as a key factor during breeding programs just to improve the synthesis of useful bioactive compounds, for example, organic acid profiles, polysaccharides composition, total phenolics. Alcaraz et al. (2017) found significant differences among different pomegranate cultivars; that is, fleshy soft seeds with high sweetness are most favorable for fresh consumption and hard seed with intense red color flesh are best suitable for juice production; high content polyphenols, high antioxidant activity, high minerals, and crude fiber are recommended for functional food. Hmid et al. (2018) also found that the cultivar type of pomegranate has a major influence on antioxidative capability, composition of polyphenols in pomegranate juices, and morphological characteristics. For commercial production of high sugar-to-acid ratios juices, growers may require diverse maturity indices to determine fruit maturity in particular cultivars (Chater et al. 2018).

Seeram et al. (2004) have emphasized that pomegranate-based foods must have in-depth studies for in vitro and in vivo toxicity of punicalagin anomers (punicalagin, punicalain, gallagic acid, and ellagic acid) as well as to establish the biological properties of these compounds.

The US Food and Drug Administration has generally recognized as safe (GRAS) to pomegranate extract. Mustafa et al. (2014) have incorporated the ellagitannins in ice cream and reported the higher percentage of acceptability by the sensory panel, which attracts to food processors for commercial introduction of ETs to produce potential functional foods. Kushwaha and Kumar (2016) have applied the pomegranate ETs in polyphenols lacking beverage and found better antioxidant activity, improved taste, and wide acceptance of product, which could be considered as a market prospective toward the production of nutraceutical beverages.

15.1.2 History

The history of pomegranate fruit is very ancient and carries many facts (Damania 2005). It is believed that the pomegranate is one among the first five crops (dates, olives, grapes, figs) that were cultivated. Cultivation of pomegranate started during 3000–4000 BC in Afghanistan, Iran, and Turkey, and after that it spread to other countries (Arjmand 2011). Pomegranate fruit is considered as a holy fruit in many religions and cultures. As per Greek mythology, pomegranate denotes life, marriage, and regeneration; in Judaism, there are 613 biblical commandments that link with 613 number of pomegranate seeds; in Buddhism, pomegranate denotes the spirit of favorable influence; in China, it is observed as a ceramic sculpture symbolizing fertility; in Christianity, it is considered as a sign of rebirth and everlasting life; and as per the Quran in Islam, it is described as four gardens with shades, springs, and fruits. Pomegranate fruits have a long shelf life in ambient conditions, which indicates the reason for its long journeys and highly uitilization in arid region and desert climate with high sustainability (Langley 2000).

15.1.3 Production

Pomegranates are widely produced throughout the world. Major producing countries are Iran, India, China, the USA, Turkey, Spain, Azerbaijan, Armenia, Afghanistan, Uzbekistan, the Middle East, Pakistan, Tunisia, and Israel, dry regions of Southeast Asia, Peninsular Malaysia, the East Indies, and tropical Africa. India is the leading country in pomegranate production. Pomegranate global-level information on area and production is not obtainable with the Food and Agriculture Organization (FAO); however, globally cultivated area of pomegranate is about 3 lakh hectares and production is 3.0 million tons (NRCP 2014). In India, pomegranates are extensively grown in Maharashtra, Karnataka, Andhra Pradesh, and Gujarat, and it is spreading rapidly in Himachal Pradesh, Madhya Pradesh, and Rajasthan. Low-cultivation areas are Tamil Nadu, Jammu and Kashmir, Mizoram, Nagaland, Jharkhand, Lakshadweep, and Odissa. In 2018–2019, the National Horticulture Board of India (NHB) has estimated the total area under cultivation of pomegranate and it is presented on the website http://nhb.gov.in (Table 15.2).

15.1.4 Botanical Description

Punicaceae family has two species, *Punica granatum L.* and *P. protopunica*. *Punica protopunica* is very common in Socotra Island of Yemen, and it is the only concentric family member of *P. granatum* species (Levin and Sokolova 1979; Zukovskij 1950; Guarino et al. 1990). *P. protopunica* has been considered as the ancestor of genus *Punica* on the basis of xylem anatomy (Shilkina 1973). Chromosome number (*n* ¼ *x*) in pomegranate is 8 or 9 (Yasui 1936; Raman et al. 1971;

Table 15.2 Pomegranate production in India

year	2016–2017		2017–2018		2018–2019 (advance estimate)	
	Area in '000 hectare	Production in metric ton	Area in '000 hectare	Production in metric ton	Area in '000 hectare	Production in metric ton
	216	2613	234	2845	246	2865

Source: NHB, INDIA

Table 15.3 Botanical classification of pomegranate

Engler and Prantl (1931)		Hutchinson (1959)	
Division:	Angiospermae	Phylum:	Angiospermae
Class:	Dicotyledonae	Subphylum:	Dicotyledonae
Subclass:	Archichlamydeae	Division:	Lignosae
Order:	Myrtiflorae	Order:	Myrtales
Family:	Punicaceae	Family:	Punicaceae
Genus:	Punica	Genus:	Punica
Species:	*P. granatum* (Linn)	Species:	*P. granatum* (Linn)

Darlington and Janaki Ammal 1945). Botanically, pomegranate fruit is classified under berry group. Pomegranate is a short tree ranging height 4–8 m and its fruit size may vary from 6 to 12 cm diameter having a hard and leathery skin. The pomegranate fruit evolved from an inferior ovary surrounded by synchronous pistil and two whorls of basal carpel present inside the receptacle. During the ovary development, the outer carpel turns out to be tilted and superimposed (Still 2006).

Pomegranate has been classified by Engler and Prantl (1931) and later on modified by Hutchinson (1959), as shown in Table 15.3. Different varieties of pomegranates are listed in Table 15.4.

15.2 Pomegranate Fruit Parts and Composition

Internal structure of pomegranate fruit is irregular in which many closely and tightly packed red arils are arranged in many segments. The irregular segments are separated by thin carpellary membrane and nonedible white-colored pith. Fruit's peel is hard and leathery and arils are attached on a fleshy and soft pith tissue. Each aril has a seed that is enclosed with edible juicy pulp.

15.2.1 Fruit

Nutritional composition and facts of pomegranate fruits have been established by the US Department of Agriculture (USDA). Nutritional facts of different edible parts of pomegranate fruits are presented in Fig. 15.1 and Tables 15.5 and 15.6.

15.3 Phytochemicals Present in Pomegranate

Most of the phytochemicals have been characterized from bark, leaves, fruits, and seed parts of the pomegranate tree displayed in Table 15.7. Polyphenols (phenolic ring with many hydroxyl groups) is the most abundant class of phytochemicals in the pomegranate fruit. Polyphenols contains proanthocyanidins (condensed tannins), ellagitannins and gallotannins (hydrolysable tannins [HTs]), flavonols, and

Table 15.4 Global pomegranate varieties and characteristic features

S. no.	Pomegranate variety	Characteristic features
1.	Wonderful	Generally, this variety grown in Florida and California. Plant is strong and highly productive. The fruit is large, oblate, red, bulky, and deep-red rind with juicy pulp, seeds are slightly hard.
2.	Kara Gul	It is grown in Turkmenistan, sweet to tart, medium to large, darkest variety in the US Department of Agriculture (USDA) collection; name means dark red/black flower.
3.	Haku Botan	It is grown in Japan, extremely tart, medium to large, yellow, tastes better after stored under refrigeration; primarily grown for ornamental double white flower.
4.	Patras Acid and Patras Douce	This variety is grown in Greece. Fruit is red, juice is red, sour and sweet
5.	Asmar	Cultivar of Israel. Fruit is dark-red-purple and blackish, with white hard seeds
6.	Ak-anarand Kizil-anar	Variety mostly found in Turkey. It is yellowish white, seeds are light red, juice is sweet to sour.
7.	Shahvar (Saveh)	Variety mostly grown in Iran, fruit red, sweet and small seeds
8.	Ganesh	It is a commercial variety in Maharashtra of India developed by the selection method. This variety has average yield 8–10 kg per tree. Fruit is a productive bearer, large fruit, yellowish red rind, pinkish aril, and soft seeds.
9.	Bhagwa	This variety is commercially grown in Maharashtra of India. Its fruit is shiny red, with soft seeds containing pulp of high T.S.S.
10.	Arakta	This variety is also very common in Indian states. Fruits are slightly smaller than the Ganesh variety. Fruit is dark red, with juicy arils having white soft seeds.
11.	Mrudula	This variety is very common in Indian states, and it has similar properties as Ganesh variety except the dark-red color of arils. The aggregate weight of fruits ranges from 250 to 300 g
12.	Muskat	This variety fruit has red rind and pink arils. Fruits average weight ranges from 300 to 350 g.
13.	Jyoti	This variety was developed at Indian Institute of Horticultural Research (IIHR), Bangalore, India. The fruits are large with attractive color having dark-red arils. The seeds are very soft with high pulp and juice contents. Fruits are grown on the inner side of the canopy and thus do not get damaged due to sun scorching
14.	Ruby	It is created at IIHR, Bangalore, India. Fruits are much similar in shape and size with "Ganesh" variety. Reddish brown rind with green streaks and red strong arils. Fruit weight ranges from 250 to 270 g with approximately 16–18 tons/ha yield.
15.	Dholka	This cultivar is popular in the Gujarat state of India. Large fruit, yellowish red rind, pinkish white juicy aril.
16.	Kandhari	Generally grown in Afghanistan. Large size fruit, deep red rind, hard seeds, fleshy testa, red, or dark-pink-colored juice having sweet and slightly acidic taste.
17.	Sindhoor	Indian variety, high productive, fruit size is medium to large, soft seeds, sweet, and fleshy red juice.
18.	Bedana	Indian variety, medium-size fruit, brownish to whitish rind, soft seeds, fleshy testa, sweet juice.

Source: Ashton (2006) and National Horticulture Board, India (2014)

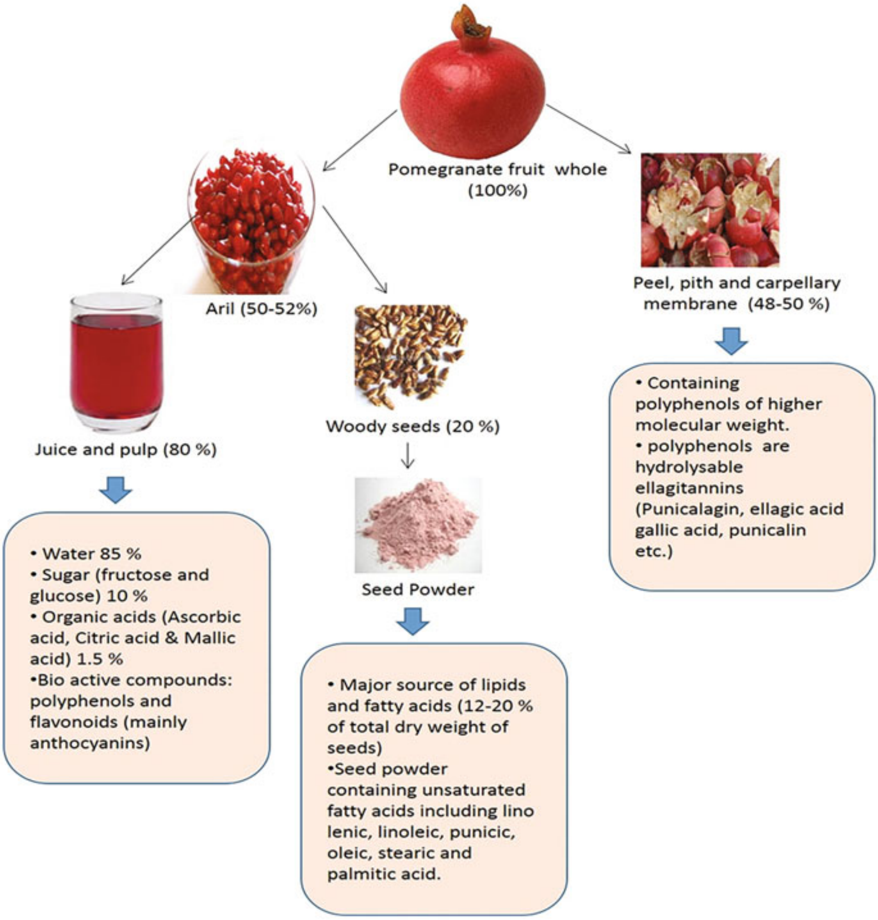

Fig. 15.1 Schematic presentation of pomegranate fruit part and their composition

anthocyanins (flavonoids) (Fig. 15.2). Phenolic acids, organic acids, alkaloids, triterpenoids, triglycerides, sterols, and fatty acids are the other phytochemicals present in pomegranate (Seeram et al. 2006a).

Plenty of flavonoids containing flavonols, for example, quercetin, kaempferol, and luteolin, are present in an extract of pomegranate peel (Elswijk et al. 2004). Anthocyanins pigment present in aril part is water soluble and accountable for color of bright red in pomegranate juice (Hernandez et al. 1999; Santagati et al. 1984). Hydrolyzable tannins are abundant in peel (husk), rind, piths, and membrane parts of fruit (Seeram et al. 2005).

Table 15.5 Nutritional composition of edible parts in pomegranate fruit (USDA 2007)

Nutrients	Value	
Water content	80.97	g per 100 g
Protein	0.95	g per 100 g
Carbohydrate	17.17	g per 100 g
Fat	0.30	g per 100 g
Energy	68	Kcal/100 g
Total sugar	16.57	g/100 g
Dietary fiber	0.6	g/100 g
Vitamin A	108	IU/100 g
α-Carotene	50	μg/100 g
β-Carotene	40	μg/100 g
Vitamin C	6.1	mg/100 g
Vitamin E	0.60	mg/100 g
Vitamin K	4.6	μg/100 g
Cholesterol	0	mg/100 g
Phytosterols	17	mg/100 g

Table 15.6 Mineral composition in edible part of pomegranate fruit (USDA 2007)

Minerals	Values (mg/kg)
Potassium	2590
Sodium	30
Magnesium	30
Calcium	30
Iron	3.0
Zinc	1.2
Copper	0.7

15.3.1 Juices

Commercial pomegranate juice (PJ) extraction is being done by hydrostatic pressing of fresh whole fruits due to which most of the phytochemicals are extracted along with the juice from all fruit parts (arils, seeds, pith, and peels). During this juice extraction process, the water-soluble polyphenolic compounds are dissolved in the juices, which contributes to the antioxidant activity of PJ (Table 15.8) (Gil et al. 2000). In commercial PJ, major polyphenols are hydrolysable tannins (HTs), flavonoids, and condensed tannins (Gil et al. 2000; Seeram et al. 2005, 2006a). HTs are key compounds responsible for approximately 92% of antioxidant capacity in PJ (Gil et al. 2000) (Table 15.9). HTs have been classified into ellagitannins (esters of ellagic acid of D-glucose with substitutions of one or more galloyl) and gallotannins (1,2,4,6-tetra-*O*-galloyl-D-glucose and 1,2,3,4,6-penta-*O*-galloyl-D-glucose) are vulnerable to nonenzymatic and enzymatic hydrolysis and consequently may be classified as per the products of hydrolysis. Punicalagin is the principal gallagyl ester of pomegranate HTs, which is responsible for about 50% antioxidant activity of the juice (Seeram et al. 2006a).

Table 15.7 Pomegranate phytochemicals (Seeram et al. 2006b)

S. no.	Name of phytochemical	Chemical formula	Molecular weight	Plant part
Ellagitannins and gallotannins				
1.	2,3-(S)-HHDP-D-glucose	$C_{20}H_{18}O_{14}$	482.35	Bark, peel
2.	Castalagin	$C_{41}H_{26}O_{26}$	934.63	Bark
3.	Casuariin	$C_{34}H_{24}O_{22}$	784.54	Bark
4.	Casuarinin	$C_{41}H_{28}O_{26}$	936.65	Bark, pericarp
5.	Corilagin	$C_{27}H_{22}O_{18}$	634.45	Fruit, leaves, pericarp
6.	Cyclic 2,4:3,6-bis (4,4′,5,5′,6,6′-hexahydroxy [1,1′-biphenyl]- 2,2′-dicarboxylate)1-(3,4,5-trihydroxybenzoate)b-D-glucose	$C_{41}H_{28}O_{26}$	936.65	Leaves
7.	Granatin A	$C_{34}H_{24}O_{23}$	800.54	Pericarp
8.	Granatin B	$C_{34}H_{28}O_{27}$	952.64	Peel
9.	Pedunculagin	$C_{34}H_{24}O_{22}$	784.52	Bark, pericarp
10.	Punicacortein A	$C_{27}H_{22}O_{18}$	634.45	Bark
11.	Punicacortein B	$C_{27}H_{22}O_{18}$	634.45	Bark
12.	Punicafolin	$C_{41}H_{30}O_{26}$	938.66	Leaves
13.	Punigluconin	$C_{34}H_{26}O_{23}$	802.56	Bark
14.	Strictinin	$C_{27}H_{22}O_{18}$	634.45	Leaves
15.	Tellimagrandin I	$C_{34}H_{26}O_{22}$	786.56	Leaves, pericarp
16.	Tercatain	$C_{34}H_{26}O_{22}$	786.56	Leaves
17.	2-*O*-galloyl-4,6(S,S)gallagoyl-D-glucose	$C_{41}H_{26}O_{26}$	934.63	Bark
18.	5-*O*-galloyl-punicacortein D	$C_{54}H_{34}O_{34}$	1222.8	Leaves
19.	Punicacortein C	$C_{47}H_{26}O_{30}$	1070.7	Bark
20.	Punicacortein D	$C_{47}H_{26}O_{30}$	1070.7	Bark, heartwood
21.	Punicalin	$C_{34}H_{22}O_{22}$	782.53	Bark, pericarp
22.	Punicalagin	$C_{48}H_{28}O_{30}$	1084.7	Bark, pericarp, peel
23.	Terminalin/gallayldilacton	$C_{28}H_{20}O_{16}$	602.37	Pericarp
Derivatives of ellagic acid				
24.	Ellagic acid	$C_{14}H_6O_8$	301.19	Fruit, pericarp, bark
25.	Ellagic acid, 3,3′-di-*O*-methyl	$C_{16}H_{10}O_8$	330.25	Seed
26.	Ellagic acid, 3,3′,4′-tri-*O*- methyl	$C_{17}H_{12}O_8$	344.27	Seed
27.	Ellagic acid, 3′-*O*-methyl-3,4-methylene	$C_{16}H_8O_8$	328.23	Heartwood

(continued)

Table 15.7 (continued)

S. no.	Name of phytochemical	Chemical formula	Molecular weight	Plant part
28.	Eschweilenol C	$C_{20}H_{16}O_{12}$	448.33	Heartwood
29.	Diellagicacidrhamnosyl(1–4) glucoside	$C_{40}H_{30}O_{24}$	894.65	Heartwood
Catechin and procyanidins				
30.	(−)-Catechin	$C_{15}H_{14}O_6$	290.27	Juice
31.	Catechin-(4,8)-gallocatechin	$C_{30}H_{26}O_{13}$	594.52	Peel
32.	Gallocatechin	$C_{15}H_{14}O_7$	306.27	Peel
33.	Gallocatechin-(4,8)-catechin	$C_{30}H_{26}O_{13}$	594.52	Peel
34.	Gallocatechin-(4,8)- gallocatechin	$C_{30}H_{26}O_{14}$	610.52	Peel
35.	Procyanidin B_1	$C_{30}H_{26}O_{12}$	578.52	Juice
36.	Procyanidin B_2	$C_{30}H_{26}O_{12}$	578.52	Juice
Anthocyanins and anthocyanidins				
37.	Cyanidin	$C_{15}H_{11}O_6$	287.24	Juice
38.	Cyanidin-3-glucoside	$C_{21}H_{21}O_{11}$	449.38	Juice
39.	Cyanidin-3,5-diglucoside	$C_{27}H_{31}O_{16}$	611.52	Juice
40.	Cyanidin-3-rutinoside	$C_{27}H_{31}O_{15}$	595.53	Juice
41.	Delphinidin	$C_{15}H_{11}O_7$	303.24	Juice
42.	Delphinidin-3-glucoside	$C_{21}H_{21}O_{12}$	465.38	Juice
43.	Delphinidin-3,5-diglucoside	$C_{27}H_{31}O_{17}$	627.52	Juice
44.	Pelargonidin-3-glucoside	$C_{21}H_{21}O_{10}$	433.38	Juice
45.	Pelargonidin-3,5-diglucoside	$C_{27}H_{31}O_{15}$	595.53	Juice
Flavonols				
46.	Apigenin-4′-*O*-β-D-glucoside	$C_{21}H_{20}O_{11}$	448.32	Leaves
47.	Kaempferol	$C_{15}H_{10}O_6$	286.24	Peel, fruit
48.	Luteolin	$C_{15}H_{10}O_6$	286.24	Peel, fruit
49.	Luteolin-3′-*O*-β-D-glucoside	$C_{21}H_{20}O_{10}$	432.11	Leaves
50.	Luteolin-4′-*O*-β-D-glucoside	$C_{21}H_{20}O_{10}$	432.11	Leaves
51.	Luteolin-3′-*O*-β-D-xyloside	$C_{20}H_{18}O_{10}$	418.09	Leaves
52.	Myricetin	$C_{15}H_{10}O_8$	318.04	Fruit
53.	Quercetin	$C_{15}H_{10}O_7$	302.04	Peel, fruit
54.	Quercimeritrin	$C_{21}H_{20}O_{12}$	464.38	Fruit
55.	Quercetin-3-*O*-rutinoside	$C_{27}H_{30}O_{16}$	610.52	Fruit
56.	Quercetin-3,4′-dimethylether7-*O*-α-L-arabinofuranosyl-(1-6)-β-D-glucoside	$C_{28}H_{32}O_{16}$	624.54	Bark, peel
57.	Eriodictyol-7-*O*-α-L-arabinofuranosyl (1-6)-β-D-glucoside	$C_{26}H_{30}O_{15}$	582.51	Leaves
58.	Naringenin 4′-methylether7-*O*-α- L-Arabinofuranosyl(1-6)-β-D-glucoside	$C_{27}H_{32}O_{14}$	580.53	Leaves
Organic acid				
59.	Caffeic acid	$C_9H_8O_4$	180.16	Juice
60.	Chlorogenic acid	$C_{16}H_{18}O_9$	345.31	Juice
61.	Cinnamic acid	$C_9H_8O_2$	148.16	Juice
62.	Citric acid	$C_6H_8O_7$	192.12	Juice

(continued)

Table 15.7 (continued)

S. no.	Name of phytochemical	Chemical formula	Molecular weight	Plant part
63.	o-Coumaric acid	$C_9H_8O_3$	164.16	Juice
64.	p-Coumaric acid	$C_9H_8O_3$	164.16	Juice
65.	Ferulic acid	$C_{10}H_{10}O_4$	194.18	Juice
66.	Gallic acid	$C_7H_6O_5$	169	Juice
67.	L-Malic acid	$C_4H_6O_5$	134.09	Juice
68.	Oxalic acid	$C_2H_2O_4$	90.03	Juice
69.	Protocatechuic acid	$C_7H_6O_4$	154.12	Juice
70.	Quinic acid	$C_7H_{12}O_6$	192.17	Juice
71.	Succinic acid	$C_4H_6O_4$	118.09	Juice
72.	Tartaric acid	$C_4H_6O_6$	150.09	Juice
Derivatives of simple galloyl				
73.	Brevifolin	$C_{12}H_8O_6$	248.19	Leaves
74.	Brevifolin carboxylic acid	$C_{13}H_8O_8$	292.2	Leaves
75.	Brevifolin carboxylic acid-10-monosulphate	$C_{13}H_7KO_{10}S$	394.25	Leaves
76.	1,2,3-tri-*O*-galloyl-β-D-glucose	$C_{27}H_{24}O_{18}$	636.47	Leaves
77.	1,2,4-tri-*O*-galloyl-β-D-glucose	$C_{27}H_{24}O_{18}$	636.47	Leaves
78.	1,2,6-tri-*O*-galloyl-β-D-glucose	$C_{27}H_{24}O_{18}$	636.47	Leaves
79.	1,4,6-tri-*O*-galloyl-β-D-glucose	$C_{27}H_{24}O_{18}$	636.47	Leaves
80.	1,3,4-tri-*O*-galloyl-β-D-glucose	$C_{27}H_{24}O_{18}$	636.47	Leaves
81.	1,2,4,6-tetra-*O*-galloyl-β-D-glucose	$C_{34}H_{28}O_{22}$	788.57	Leaves
82.	1,2,3,4,6-pent-*O*-galloyl-β-D-glucose	$C_{41}H_{32}O_{26}$	940.68	Leaves
83.	Methyl gallate	$C_8H_8O_5$	184.15	Heartwood
84.	3,4,8,9,10-pentahydroxy-dibenzo[b,d] pyran-6-one	$C_{13}H_8O_7$	276.20	Leaves
Alkaloids				
85.	Hygrine	$C_8H_{15}NO$	141.21	Root bark
86.	Norhygrine	$C_7H_{13}NO$	127.18	Root bark
87.	Pelletierine	$C_8H_{15}NO$	141.21	Bark
88.	*N*-methylpelletierine	$C_9H_{17}NO$	155.24	Bark
89.	Sedridine	$C_8H_{17}NO$	143.23	Bark
90.	Pseudopelletierine	$C_9H_{15}NO$	153.22	Bark
91.	Norpseudopelletierine	$C_8H_{13}NO$	139.19	Bark
92.	2,3,4,5-tetrahydro-6-propenyl-pyridine	$C_8H_{13}N$	123.20	Bark
93.	3,4,5,6-tetrahydro-a-methyl-2-pyridine ethanol	$C_8H_{15}NO$	141.21	Bark
94.	1-(2,5-dyihydroxy-phenyl)-pyridiumchloride	$C_{11}H_{10}ClNO_2$	223.66	Leaves
Other compounds				
95	Coniferyl 9-*O*-[β-D-apiofuranosyl-(1-6)]-*O*-β-D-glucopyranoside	$C_{21}H_{30}O_{12}$	474.46	Seed
96.	Sinapyl 9-*O*-[β-D-apiofuranosyl-(1-6)]-*O*-β-D-glucopyranoside	$C_{22}H_{32}O_{13}$	504.48	Seed

(continued)

Table 15.7 (continued)

S. no.	Name of phytochemical	Chemical formula	Molecular weight	Plant part
97.	Phenylethyl rutinoside	$C_{20}H_{30}O_{10}$	430.45	Seed
98.	Icariside D1	$C_{19}H_{28}O_{10}$	416.42	Seed
99.	Mannitol	$C_6H_{14}O_6$	182.17	Bark

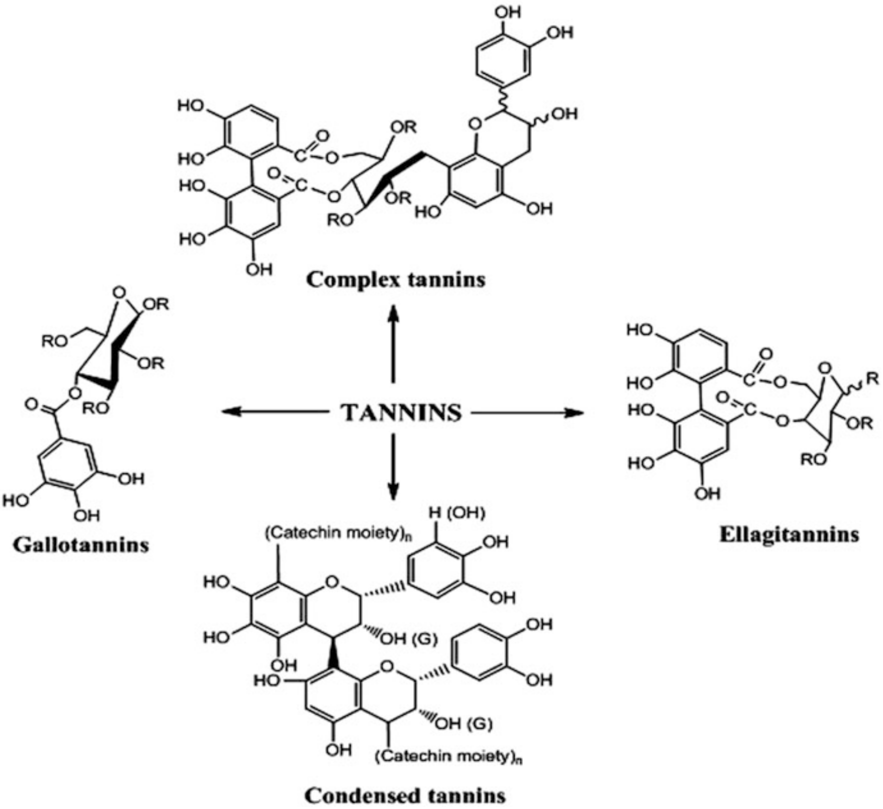

Fig. 15.2 Classification of tannin (Khanbabaee and van Ree 2001)

15.3.2 Seed

Seeds are by-product remains after juice extraction from pomegranate. Commercially produced juice also contains the extracts of seeds due to which many beneficial properties such as higher antioxidant capacity, antibacterial properties, high minerals, and plenty of fatty acids exist in juices. Pomegranate whole seeds (dried) are easily available in national markets of India. Seeds obtained from wild variety (*Daru*) of pomegranate from Himalayan regions have been considered as quality sources for the spices (Jindal and Sharma 2004; Stover and Mercure 2007). Dried

Table 15.8 Composition of phenolic compounds in different PJ (Gil et al. 2000)

Polyphenolic compounds	Pomegranate juices extracted by crushing whole fruit			
	PJ From frozen arils	PJ from concentrate	PJ (single strength)	Fresh juice
Anthocyanins	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Cyanidin 3-glucoside	59.5	67.0	151.1	128.3
Delphinidin 3-glucoside	23.6	37.8	95.2	76.0
Cyanidin 3,5-diglucoside	46.4	31.4	71.4	53.0
Delphinidin 3,5-diglucoside	38.8	21.1	61.1	42.9
Pelargonidin 3-glucoside	3.9	4.6	8.5	5.9
Total anthocyanins	172.2	161.9	387.4	306.0
Gallagyl-type tannins				
Punicalagin D	11.1	918.2	838.5	10.1
Punicalagin B	14.4	434.9	421.3	12.7
Others	102.5	525.6	302.0	45.1
Total gallagyl tannins	128.1	1878.8	1561.7	67.9
Ellagic acid derivatives				
Ellagic acid	8.7	172.8	37.9	15.3
Ellagic acid glucoside	17.9	91.3	83.2	17.9
Total ellagic derivatives	26.5	264.0	121.1	33.2
Other hydrolyzable tannins				
Compound C	203.6	229.0	116.5	224.5
Galloyl glucose	43.9	65.5	49.3	51.1
Other compounds	277.7	262.1	251.5	264.1
Total hydrolyzable tannins	525.2	556.6	417.3	539.2

Table 15.9 Antioxidant activity of single strength PJ (Gil et al. 2000)

Fractions	Different method of antioxidant activity		
	FRAP	DPPH	DMPD
Ion-exchange resin, retained	72.3	71.1	36.8
Ion-exchange resin, nonretained	27.7	28.9	63.0
Nonretained fraction separated by C-18 solid-phase extraction cartridge			
Methanol extract	27.7	26.4	15.2
Water extract	0.0	0.0	74.6

FRAP; method of antioxidant activity based on the ferric reducing ability of plasma at low pH (Benzie and Strain 1996). DPPH; 2,2 diphenyl1-picrylhydrazyl, a standard of free radicals, soluble in methanol and measured the absorbance at 515 nm to calculate the antioxidant activity (Brand-Williams et al. 1995), DMPD; It is a radical-scavenging method in which absorbance was measured at 505 nm after addition of Fe^{3+} to *p*-phenylene diamine (Fogliano et al. 1999).

Table 15.10 Nutritional values of pomegranate seeds

Components	Values	
Moisture	8.60	g/100 g
Ash	2.00	g/100 g
Crude protein	13.2	g/100 g
Total fat	27.2	g/100 g
Carbohydrates	49.0	g/100 g
Energy	493.6	Kcal/100 g
Crude fiber	35.3	g/100 g
Total sugar	4.2	g/100 g
Pectin	6.0	g/100 g
Vitamin C	10.2	mg/100 g
Vitamin B_6	0.08	mg/100 g
Foliate	37.93	µg/100 g
Vitamin K	16.44	µg/100 g
Potassium	235.6	mg/100 g
Magnesium	12.4	mg/kg
Phosphorus	35.6	mg/100 g
Iron	1.3	mg/kg
Copper	1.2	mg/kg
Zinc	1.0	mg/kg
Fatty acids composition of pomegranate seed oil		
Punicic acid	65.3	g/100 g
Caproic acid	2.16	g/100 g
Capric acid	0.95	g/100 g
Oleic acid	5.13	g/100 g
Linoleic acid	6.6	g/100 g
Lauric acid	6.62	g/100 g
Myristic acid	7.56	g/100 g
Myristoleic acid	0.41	g/100 g
Palmitic acid	4.8	g/100 g
Palmitoleic acid	0.47	g/100 g
Stearic acid	2.3	g/100 g

Source: Seeram et al. (2006a), El-Nemr et al. (1990), Bhandary et al. (2012) and El-bandy and Ashoush (2012)

g = gram, mg = mili gram, µg = micro gram, kg = kilo gram

seeds are highly useful for many culinary applications. Nutritional composition, including proximate, minerals, and fatty acids, are shown in Table 15.10. Punicic acid is the main fatty acid among all fatty acids present in pomegranate seed oil. Punicic acid is a conjugated linoleic acid having potent biological properties (Carvalho 2014). Pomegranate seeds may provide 12% vitamin C, 16% vitamin K, 10% folate, and 20% dietary fiber of the daily value required (Schubert et al. 1999).

15.3.3 Peels

Pomegranate peels are abundant by product after juice extraction that attracts attention towards its apparent antioxidative capacities (Tzulker et al. 2007), wound healing properties (Chidambara et al. 2004), antibacterial activity (Navarro et al. 1996), immune modulatory activity (Gracious et al. 2001), antiatherosclerotic, and other functional properties. Antioxidant activity is well evident to reduce the risk of many diseases (Whitley et al. 2003). In recent studies it has been found that pomegranate peels are a major source of ellagitannin that may serve to control the cattle diseases and improves the health and beef products when fed as cattle feed. Cattle feed packed with pomegranate peels has shown the weight- and health-boosting effects of hormones and antibiotics without any negative effects and also obtained high-quality antioxidants-rich meat (Shabtay et al. 2008). It has been observed that pomegranate peels have higher antioxidant capacity in comparison with the aril juice (Li et al. 2006; Tzulker et al. 2007). High antioxidant capacity of pomegranate peel is specifically contributed by the hydrolysable tannins and anthocyanins (Gil et al. 2000; Tzulker et al. 2007). High antioxidant activity of pomegranate peel and its extract indicates a strong link against lipid oxidation for the antiatherogenic effects on lipoproteins (Labib and Hossin 2009). Nutritional composition (Table 15.11) of fresh pomegranate peel and detanninated pomegranate peel powder were determined by Kushwaha et al. (2013) to explore it as a nutritional supplement for cattle feeds.

15.3.4 Antioxidant Properties of Products Prepared From Pomegranate Ellagitannin (ETs)

El-Said et al. (2014) have found in their study that when aqueous extracts of pomegranate peel are added to yoghurt, it results in a proportional increment in antioxidant activity (up to 25%) without any significant effect on sensory attributes. Ellagitannin powder (ETP) obtained from fresh pomegranate peel was added to *sharbet* (sugar syrup-based drink) and found that antioxidant activity (as DPPH radical scavenging) had improved by 12–75%. Addition of ellagitannins powder to *sharbet* exhibited significant positive effects on taste, color, odor, and pH. However, ellagitannin concentration beyond 40 mg per 100 ml is not recommended to avoid adverse effects on taste and odor. *Sharbet* containing ellagitannin powder (30–40 mg/100 ml) and lemon extract was a highly accepted product by sensory panel. Thus, this study lends credence towards the fact that the use of ellagitannin in polyphenols deficient food could be a potential for nutraceutical food market (Kushwaha and Kumar 2016). Hathairat Rimkeeree et al. (2017) have applied the pomegranate peel extract in the form of encapsulated alginate beads in pomegranate jelly and found that antioxidant activity of jelly has increased along with consumer acceptance. Ramezanalizadeh et al. (2018) have presented in their study that pomegranate vinegar has potential to prevent or control the proliferation of *Streptococcus mutans* and *Streptococcus sobrinus.*

Table 15.11 Nutritional composition of fresh and detanninated pomegranate peel powder (Kushwaha et al. 2013)

Components	Fresh peel powder	Detanninated peel powder
Dry matter (g/100 g)	30.57	17.63
Ash (g/100 g)	5.49	3.29
Ether extract (g/100 g)	2.4	1.43
Crude protein (g/100 g)	3.95	6.43
Crude fiber (g/100 g)	12.61	24.36
Neutral detergent fiber (g/100 g)	17.83	28.54
Acid detergent fiber (g/100 g)	14.55	26.11
Lignin (g/100 g)	4.29	7.59
Nitrogen free extract (g/100 g)	75.54	64.49
Total polyphenol content (mg/g)	40.53	1.11
Vitamin A (μg/g)	14.06	11.04
Sodium (mg/kg)	763.66	362.74
Potassium (mg/kg)	16237.41	6679.50
Calcium (mg/kg)	645.70	728.23
Magnesium (mg/kg)	1644.47	524.80
Phosphorus (mg/kg)	33.96	57.01
Iron (μg/g)	22.6	18.33
Copper (μg/g)	6.2	4.67
Zinc (μg/g)	8.03	9.63

15.4 Characterization of Chemical Compounds Accountable for Antioxidant and Biological Activities

Characterization of dark-brown color ellagitannin powder (ETP) prepared from water extract of pomegranate peel was carried out by Fourier transform infrared spectroscopy (FTIR), UV-Vis absorption of 10 ppm aqueous methanolic (1:1) solution, chromatographic characterization by high-performance liquid chromatography (HPLC), and mass ion (*m/z*) characterization by liquid chromatography mass spectrometry (LCMS) with respect to standards of major polyphenolic compounds, that is, ellagic acid (EA), gallic acid (GA), and punicalagin (PU). Particular wave numbers of FTIR spectrum have indicated the presence of different acidic, phenolic, hydroxyl, and hydrocarbon compounds. UV-Vis spectrum of ETP has exhibited λ_{max} (213 nm), which is equivalent to λ_{max} of standard GA. HPLC chromatogram of ETP has shown the characteristic peaks as GA, EA, and PU at retention time (RT) 4–6 min, 12–14 min and 8–10 min respectively. LCMS scan spectra of ETP has confirmed the presence of EA (*m/z* 301), GA (*m/z* 169), and PU (*m/z* 541) along with pentoside (*m/z* 432), hexoside (*m/z* 770), and glucoside (*m/z* 472) of EA. Physicochemical properties of ETP were analyzed to have detailed information about color (L,a,b: 49.42, 18.34, 9.89), odor (characteristic), taste (stringent), pH of 1% aqueous solution (3.82), solubility at pH 2, 4, 6, 8, and 10 (>99%), density (0.910 g/ml), wettability (144 s), hygroscopicity (3.86%), water activity (0.292), inorganic matter

(0.03%), and antioxidant activity (94.47% RSA as DPPH). ETP was also evaluated for thermal degradation by thermogravimetric analyzer (TGA), heat capacity (ΔC_p), and glass transition (T_g) temperature by differential scanning calorimeter (DSC) to establish the thermal properties of ETP for its food application. Total mass change of 44.33% has shown its more heat stability. Glass transition temperature and heat capacity of ETP were 152.5 °C and 4.633 J/g, respectively. Hence, ETP prepared from pomegranate peel water extract is more suitable for high-temperature processing.

In view of functional characterization of ETP, the antibacterial activity (bacterial growth inhibition) was observed against various food pathogen bacteria. Minimum inhibitory concentration (MIC) of ETP was 2 mg/ml against the *Escherichia coli, Bacillus subtilis, Pseudomonas aeruginosa,* and *Staphylococcus aureus,* while MIC of ETP was 4 mg/ml against the *Salmonella typhimurium.* Since animal experiments are expensive and involved complicated ethical issues; hence, in vitro toxicity of ETP was carried out in HeLa cell line by alamarBlue Assay. Results indicated IC_{50} of 92 mg/ml, which is safe at low dose. Hence the study by Kushwaha (2016) reveals that ETPs prepared from fresh pomegranate peel have desirable physicochemical, thermal, and antibacterial properties with low toxicity. Hence water extraction of ETs from fresh pomegranate peel may be followed for preparation of ETP as a common agro-waste processing practice. Seeram et al. (2006b) have summarized the pathways through which pomegranate polyphenolic compounds reduce the formation of macrophage foam cell and advanced atherosclerosis development (Fig. 15.3).

15.5 Health Benefits

Pomegranate fruits have revealed important prevention power for cancer by regulation of cell death mechanism and cell defense process. These chemopreventive effects may be due to the synergistic effects of various phenolic compounds (Akpinar-Bayizitet al. 2012) (Fig. 15.4).

It has been found that routine intake of pomegranate juice can control the myocardial ischemia induced by stress in patients with coronary heart disease (CHD). Pomegranate juice consumption reduces the damage of blood vessels and hence prevents the hardening of arteries (Sumner et al. 2005). Polyphenols present in pomegranate juices are responsible for neural protection and highly effective against Alzheimer's disease (Hartman et al. 2006). Some important health benefits are as follows:

- Antioxidant activity
- Prevention of skin, prostate, breast, and colon cancer
- Anti-inflammatory activity
- Cardiovascular health
- Antidiabetic properties (regulation of glucose and lipid metabolism activity)
- Antimicrobial properties

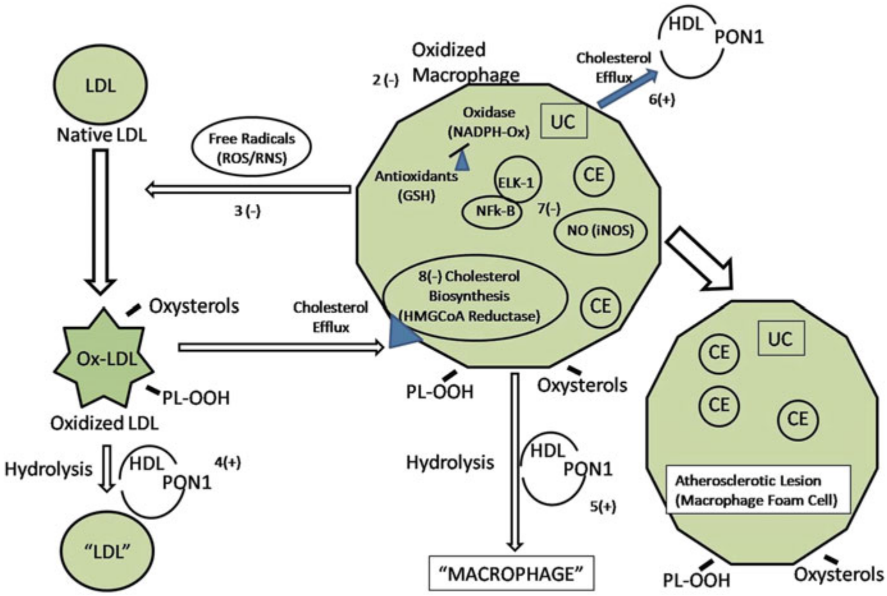

Fig. 15.3 Major pathways by which pomegranate polyphenols inhibit macrophage foam cell formation and atherosclerosis. Pomegranate juice (PJ) polyphenols affect LDL directly by their interaction with the lipoprotein and inhibition of LDL oxidation (1). PJ polyphenols can also protect LDL indirectly, by their accumulation in arterial cells and protection of arterial macrophages against oxidative stress (2). This latter effect is associated with inhibition of the formation of "oxidized macrophages" and reduction in the capacity of macrophages to oxidize LDL (3). In addition, PJ polyphenols preserve or even increase paraoxonase activity, thereby increasing hydrolysis of lipid peroxides in Ox-LDL ("LDL") (4) or in oxidized macrophages in the atherosclerotic lesion ("Macrophage") (5), or increasing HDL-mediated efflux from macrophages (6), leading to attenuation in the progression of atherosclerosis. PJ polyphenols can also reduce the oxidative capacity of macrophages by reducing the activation of the redox-sensitive genes ELK-1 and NFκ -B, and increasing activation of inducible NO (iNOS) (7). Furthermore, PJ inhibits cholesterol biosynthesis in macrophages (8), thus reducing cholesterol accumulation in macrophages and their conversion into foam cells. *ROS* reactive oxygen species, *RNS* reactive nitrogen species, *PL-OOH* phospholipid hydroperoxides, *S-R* scavenger receptors, *CE* cholesterol ester, *UC* unesterified cholesterol, *NO* nitric oxide, *iNOS* inducible nitric oxide synthase; (+), stimulation; (−), inhibition (Source: Seeram et al. 2006b)

15.6 Conclusion

It is evident that pomegranate fruit is an ancient fruit having great therapeutic value both in vivo and in vitro. It has been utilized in food industry for producing different nutraceutical food. It has no toxic effects to human consumption even taken up to 1400 mg of pomegranate extract and can be used as a natural supplement. Although there is a need of the time to promote the cultivation of commercial varieties of pomegranates by professional means in order to gain benefits of this fruit.

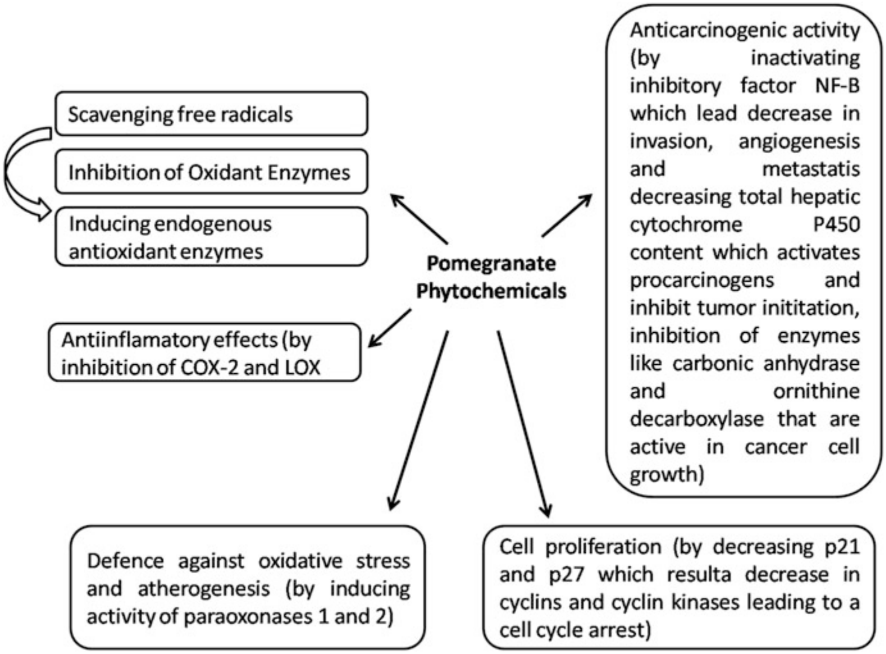

Fig. 15.4 Bioactive effects of pomegranate constituents (Akpinar-Bayizit et al. 2012)

Pomegranate peels are rich source of ellagitannin. Detanninated pomegranate peel powder contains plenty of nutritional compounds which can be utilized as cattle feed supplements. Ellagitannin obtained from fresh pomegranate peel have desirable physicochemical, thermal, and functional properties that can be applied effectively as additives (nutraceutical, antioxidative, antibacterial biopreservative, and coloring agent) in different food system.

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Tamarind (*Tamarindus indica*)

16

Barsha Devi and Tridip Boruah

Abstract

Tamarindus indica is recognized highly around the world for its nutritional and high health promotion values. In the recent past, antioxidants from natural sources and their roles in prevention and treatment of various ailments have been extensively studied. Wide distributions of polyphenol and flavonoid compounds in *Tamarindus indica* are believed to be responsible for its high antioxidant activity. Phenolic compounds present in tamarind are beneficial for cardiovascular health and immunological health and have specific roles in antimicrobial and anticancer activities. The flavonoids present in different parts of tamarind are known to exhibit defence mechanism as an anti-inflammatory, antidiabetic and antihyperlipidemic agent for the treatment of several human health hazards. Although a huge amount of data is available in the literature concerning the antioxidant properties of *Tamarindus indica*, this chapter is an attempt to compile all those information in a single platform to aid the future direction of this research area.

Keywords

Tamarind · Health benefits · Antioxidants · Polyphenol · Fruit pulp · Flavonoids

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16.1 Botanical Name, Common Name

Botanical name: *Tamarindus indica* Linn
Common name: Teteli (Assamese), Imli (Hindi), Tamarind (English)

16.2 Introduction

Tamarindus indica L. is one of the chief leguminous plant species of Fabaceae family. Almost each and every part of this plant has some use in medicinal, nutritional, economic, or environmental context. Therefore, it is regarded as a multipurpose tree. Although it is capable of tolerating a dry condition of 5–6 months long duration, but it has a very minimal amount of chance in surviving at stumpy temperature (Pereira et al. 2011). The diverse varieties of tamarind can be further divided into two distinct types—acidic variety and sweet acidic variety. The former variety easily develops under warm and sunny locations and therefore is most common. The latter, which is a sweet-type variety, is more sensitive to fluctuations in temperature and so not readily available. Tamarind has a great demand towards its fruits that are either consumed as fresh raw material or processed. The mouth-watering sweet acidic taste of tamarind pulp is due to balanced combination of tartaric acid and reducing sugar content. Pulp has various utilities such as seasoning, flavour confections, curries, chutneys, sauces, juice, infusion, brine, or beverage. Seeds of tamarind are the by-products of various industries that use tamarind pulp as their raw material. An occurrence of an elevated amount of chemicals such as tannins as well as various dyeing substances in the testa makes the entire seed unpleasant for direct consumption (Kumar and Bhattacharya 2008). Therefore, seeds are first soaked and boiled in water before consumption. A well-known product known as tamarind kernel powder or TKP is the foremost industrial product of tamarind seed industry. TKP has various utilizations such as a raw material in the jute and paper industries, initial sizing material of the fabric and textile industry (Kumar and Bhattacharya 2008). Jellose, which is a polysaccharide isolated from its seed, is utilized as a stabilizer in cheese as well as mayonnaise and ice cream and in the manufacturing of pharmaceutical product. In some developing countries, tamarind seeds can serve as a substitute protein source to lessen malnutrition problems. Flowers and leaves can be eaten fresh, cooked in a variety of dishes, or can be prepared into curries, salads and soups. So, basically this plant has huge potential in eradicating many problems associated with human health and that's why a compiled review of the work done on this plant is an extremely necessary step for providing a direction to the future researchers.

16.2.1 Origin and History

Various authors have anticipated different geographical areas for the origin of tamarind like Far East or Africa (Coates-Palgrave 1988) or Ethiopia (Troup 1921). But the fact is that tamarind is aboriginal to Africa and exotic to Central America and the Asian subcontinent. However 'Tamarind' word itself is a Persian word derived from 'tamar-i-hind' meaning 'date of India'. Moreover, the presence of tamarind is indicated in the historic Indian Brahma Samhita scriptures way before between 1200 and 200 BC (El-Siddig 2006). Therefore many natural scientists including Morton and Dowling (1987) thought it to have been originated from India. The dispersal of tamarind to Asia is thought to have occurred in the first millennium BC. Later, the development of cultivation techniques for tamarind was acknowledged in the country of Egypt by 400 BC. It is believed that Arab and Persian merchants brought tamarind to South East Asia from India.

16.2.2 Production

Among Asian countries, India and Thailand are the leading tamarind producers followed by Indonesia, Sri Lanka, Bangladesh and Thailand. Apart from that, Mexico and Costa Rica are the prime producers of Tamarind in America. Although in Africa tamarind has its wide uses among the local people but no commercial productions have been reported so far. Trivial producers in Africa are Zambia, Kenya, Senegal, Tanzania and Gambia (El-Siddig 2006). An interesting observation can lead us to the fact that India is the only country in the world to produce tamarind as fruit of commercial crop. Within the country, tamarind is abundantly cultivated in Tamil Nadu, Andhra Pradesh, Madhya Pradesh, Odisha, Karnataka, Kerala, Bihar and West Bengal. India recorded a yield of 188,278 tonnes of tamarind in the year 2007–2008 and 193,873 tonnes in the year 2008–2009 (Rao and Mathew 2012). Tamil Nadu accounted for the largest volume of tamarind production in the year 2018, followed by Kerala and Maharashtra. About 5.5 million tonnes of Tamarind fruit have been marketed widely within India and about 70,000 tonnes have been exported annually. India exported 97,000 tonnes of fresh and dried tamarind worth Rs. 14 crores to West Asia, Europe and America during 1996–1997. For the purpose of marketing, salt has been replaced by sugar to ensure its preservation and preparation. This sweet pulp is exported to countries such as the USA and Europe to be used in confectionery. After India, Thailand holds the second position as a leading tamarind producer with a record of 140 thousand tonnes production margin (Yaacob and Subhadrabandhu 1995). Production and export of tamarind from other Asian countries take place at much lesser scale as compared to Thailand and India. Out of the total world production of tamarind, sour variety is most widespread comprising 95%. Thailand is considered as the world's biggest producer of sweet tamarind.

16.2.3 Botanical Description

Tamarind is a hefty, evergreen, or semi-evergreen tree of 12–14 m high with a thick trunk up to 1.5–2 m across and up to 8 m in circumference. Leaves are alternate and even pinnate, 5–12.5 cm long, shortly petioled and petiole glabrous or puberulent. Leaflets are subsessile, 10–12 paired, closely set on the rachis, oblong, obtuse, glabrous and reticulately veined. Flowers are few, borne in racemes at the ends of branches, the lateral flowers are dropping. Flowers bisexual, irregular with a pedicel (5–10 mm) are connected at the apex. Bracts are early caduceus and ovate oblong. There are two small bracteoles, boat-shaped and reddish. Calyx (8–15 mm long) with a very constricted turbinate tube with four unequal sepals, imbricate, ovate and membranous in nature. Corolla of five petals with two anterior and three upper; the upper petals are more or less longer than the sepals while the anterior petals are found as bristle embedded in the basal portion of the staminal tube Out of all the seven stamens, three are fertile and rest four are sterile. Anthers are reddish brown in colour, oblong in nature, transverse and dehisce longitudinally. The position of ovary is superior to other floral parts with few to numerous ovules, stalked. The fruits are pods, 5–16 cm long and 2 cm broad, oblong, curved or straight, compressed. The outer epicarp of pod exhibits a brown or light grey colour and scaly. The pulp inside is soft and blackish brown in colour. Each of the pod contains up to 3–12 obovate, oblong mature seeds. Seeds are hard, and colour varies from slightly reddish to purplish brown, exalbuminous with thick cotyledons.

16.3 Antioxidant Properties of *Tamarindus indica*

Antioxidants are the substances that inhibit the oxidation process of the targets even at low concentration and thus acting as body's endogenous defence system against free radicals. These antioxidants can be grouped into two broad categories—natural and synthetic antioxidants. According to some researches in the recent past, the use of synthetic antioxidants has shown their unwanted side effects, so extensive use of such materials may cause potential health risk in the near future (Kaur and Kapoor 2001). Therefore, nowadays people are more interested towards natural antioxidants rather than synthetic products. Natural antioxidants primarily include polyphenols that present in almost every portion of the plants such as barks, fruits, leaves, nuts, roots and seeds. Flavonoids (a subclass of polyphenol) are second most important natural antioxidants (Lu et al. 2011). Vitamins, for instance, vitamin C (ascorbic acid) and vitamin E (Tocopherol), carotenoids are furthermore known to have antioxidant potentials. *Tamarindus indica* is known to have remarkable antioxidant property. Different parts of tamarind such as fruit pulp, pericarp, seed and leaves are natural sources of antioxidants that can be an alternative to synthetic antioxidants. Different antioxidant compound identified from various parts of tamarind along with the antioxidants present in their products are described below.

16.3.1 Seed

Tamarind is an admirable supply of natural antioxidants such as phenolic compounds and flavonoids. Polyphenols are the most noteworthy compounds responsible for antioxidant properties of plant raw material (Buck Up and Samappito 2011). Tsuda et al. (1994) reported four phenolic compounds from seeds of tamarind, which are 2-hydroxy-3′, 4′dihydroxyacetophenone, methyl 3,4-hidydroxybenzoate, epicatechin and 3,4-dihydrophenyl acetate. Furthermore, they have reported that these extracts exhibited antioxidant activities by plummeting lipid peroxidation in vitro. Later on, Lakhe et al. (2017) confirmed the antioxidant property of tamarind seed extract through peroxide value and Kreis test. Caffeic acid is the most important compound in seed extract responsible for its antioxidant properties protecting cells against lipid peroxidation (Razali et al. 2015). Methanolic extracts obtained from tamarind seed coat have the potential to restore activity of antioxidants of enzymatic origin such as catalase of carbon tetrachloride (CCl_4)-induced oxidative damage in albino rats in vitro and superoxide dismutase (Sandesh et al. 2014). They suggested that these products could be used as health supplement, nutraceutics as well as food preservative. Because of the occurrence of flavonoids, phenols and tannins, the extracts from seed coat possess a number of activities such as lipid peroxidation, diminution, antimicrobial, antihyperlipidemic, antidiabetic, antityrosinase, collagen stimulating, anti-inflammatory (Soradech et al. 2016). Not only the raw seed coats but also the phenolic substances from the dry heated seed coats are potent antioxidant source (Siddhuraju 2007). Even the tamarind seed husk has high content of phenolic compounds and antioxidant activities as reported by many researchers (Povichit et al. 2010; Sinchaiyakit et al. 2011).

16.3.2 Pericarp

The outermost layer, that is, exocarp is variously known as skin, pericarp, peel, or husk of a fruit. Polyphenolic profile of methanolic extract of tamarind pericarp mostly contains proanthocyanidins (73.4%) such as (þ)-catechin, taxifolin, procyanidin trimer, luteolin, epicatechin, naringenin of total phenols, procyanidin B_2, apigenin, eriodictyol and tetramer, pentamer and hexamers of procyanidin as a whole (Sudjaroen et al. 2005). Pumthong (1999) also found extracts of tamarind pericarp to be dominated mainly by polymeric tannins and oligomeric procyanidins.

16.3.3 Fruit Pulp

The pulp constitutes most part (25–50%) of the mature fruit of tamarind, the fibre and shell constitute 10–30% and the seed constitutes about 25–45% (El-Siddig et al. 1999). Fruit pulp of *Tamarindus indica* is a rich source of phytonutrients, including phenolic compounds that have the potential to act like proper dietary antioxidants. It is a prosperous resource of polyphenols such as flavan-3-ols (epicatechin and catechin), flavonoids (vitexin, iso-vitexin), procyanidin, triterpenes (orientin, iso-orientin) and vitamins (B3, E and C) (Narina et al. 2019). When flesh of tamarind was compared with other fruits such as avocado, jackfruit, mango and longan, it showed the highest phenolic content (Soong and Barlow 2004). Moreover, fruit extract obtained from tamarind boosts up and triggers the antioxidant defence coordination of the body. Raw extract of pulp, when administered on model animals in laboratory, largely enhanced the efficiency of certain enzymatic antioxidants such as superoxide dismutase and glutathione peroxidase (Lim et al. 2013; Martinello et al. 2006). Fruit pulp extract of tamarind caused 50% lowering in the initial level of serum total cholesterol, 73% lowering of non-high-density lipoprotein (non-HDL) cholesterol, 60% triglyceride reduction and an enhancement up to 61% in case of high-density lipoprotein level during an in vitro experiment performed on hypercholesterolemic hamster. The experiment showed free radical scavenging activity of the obtained extract as proved by 2–2-diphenyl-1-picrylhydrazyl (DPPH), low lipid peroxidation in serum, and radical superoxide assays (Martinello et al. 2006). Fruit pulp is a rich source of organic acids. Among all the chemical constituents of tamarind, tartaric acid is most abundant. The acidic taste of tamarind is due to the existence of high concentration of tartaric acid in various parts (El-Siddig et al. 1999). Other organic acids comprise succinic acid, malic acid, formic acid, oxalic acid, acetic acid and citric acid (Katsayal et al. 2019).

16.3.4 Leaf

Antioxidant activities of tamarind leaf have been highlighted by many researchers (Mbaye et al. 2017; Selvi et al. 2011). Flavonoids and tannins are the main constituent of tamarind leaf (De Caluwé et al. 2010). Methanolic extracts of leaf show 80% phenol, 60–70% flavonoids and 50% tannin content (Selvi et al. 2011). These abundant polyphenolic constituents are responsible for the antioxidative activities of its leaves. HPLC-UV spectroscopy analysis of leaf extracts identified six flavonoids derivatives—Luteolin 7-o-glycosides, luteolin, apigenin, isorientin, orientin, vitexin and one polyphenol derivative derivative—caffeic acid (Escalona-Arranz et al. 2010). Gas chromatography-mass spectrometry (GC-MS) analysis of leaf extracts also showed the presence of sterols and phenolic compounds. Those compounds are limonene, naringin, caryophyllene, p-cymene and ß-sitosterol (Escalona-Arranz et al. 2010). Limonene and naringin are the two well-known phenolic compounds in citrus fruits having antioxidant activities (Bacanli et al. 2015). ß-Sitosterol is a naturally occurring sterol molecule mostly found in legumes, cereals, plant oil, seed and nuts. It has potential to inhibit the growth of specific type of tumour cell in vitro. ß-Sitosterol was seen to prevent lipid peroxidation and restore the activity of nonenzymatic antioxidants to normal function in a DMH (1,2-dimethylhydrazine)-mediated colon carcinogenesis in Wistar rats (Baskar et al. 2012). Glycosides are also known to have antioxidant potential. A good figure of glycosides such as isoorientin, isovitexin, vitexin and orientin have been extracted from the leaves of tamarind (Bhatia et al. 1966). Leaves of tamarind are known to be a very rich source of ascorbic acid or vitamin C (El-Siddig 2006).

16.3.5 Juice Concentrate

Tamarind juice is a wealthy supply of antioxidant that boosts up body's immune system. It is a very rich resource for ascorbic acid, which acts as a blood purifier. Regular consumption of juice extracts of *Tamarindus indica* prevents the body from oxidative damage. It has the inherent capacity to prevent the entire process of oxidation of cholesterol, thus preventing them by adhering to the walls of arteries and finally jamming them in the process. This will, in turn, lessen the threat of high cholesterol level and coronary heart disease (Maheshwari et al. 2014). The approximate composition of juice concentrate as reported by Central Food Technological Research Institute, that is, CFTRI is enumerated later:

Invert sugars 50%
Total tartaric acid 13%
Moisture content 30%
Protein 3%
Pectin 2%
Cellulosic material 2%

16.3.6 Antioxidant Properties of Products Obtained From *Tamarindus indica*

Tamarind kernel powder (TKP) is the final product of tamarind seed industry. TKP is incorporated during preparation of baked products such as cake and biscuits in order to improve nutritional content and increase shelf life. TKP-incorporated baked products showed increased shelf life that might be due to its potent antioxidant properties (Chakraborty et al. 2016). Pectin is a very much naturally occurring polysaccharide in the plant body. It is extensively engaged as stabilizing emulsifying and gelling agent (Koubala et al. 2008). Pectin isolated from tamarind pulp is known to exhibit antioxidant potential. Its antioxidant activity is higher than or similar to tamarind seed, pulp, or seed coat (Sharma et al. 2015). Rodriguez Amado et al. (2016) formulated and standardized a new tablet from tamarind leaf. They evaluated antioxidant and hepatoprotective potential of the formulation on a Sprague Dawley rats intoxicated with CCl_4. They found that redox balance of all enzymatic antioxidants remained normal and lipid peroxidation is inhibited in the experimental groups treated with tablets. Xyloglucan is a natural polysaccharide obtained from tamarind seed kernel. This polysaccharide has a range of applications in areas like medicine industry, textile industry and food and drug delivery technology (Mishra and Malhotra 2009). Xyloglucan exhibits strong antioxidant, antimutagenic and anticarcinogenic activity along with gallic acid (Hirun et al. 2015). Tril et al.

Table 16.1 Various antioxidant compounds isolated from different parts of *Tamarindus indica*

Various parts	Compounds	References
Seed	2-Hydroxy-3′,4′dihydroxyacetophenone, methyl 3, 4-hidydroxybenzoate, 3,4-dihydrophenyl acetate, epicatechin, and caffeic acid	Tsuda et al. (1994), Razali et al. (2015).
Pericarp	Naringenin, taxifolin, (þ)-catechin, luteolin, eriodictyol, epicatechin, apigenin, procyanidin B_2, and trimers-tetramers-pentamers-hexamers of procyanidin.	Sudjaroen et al. (2005)
Fruit pulp	Catechin, epicatechin, vitexin, iso-vitexin, procyanidin, orientin, iso-orientin, vitamins (B_3, E, C), formic acid, oxalic acid, acetic acid, malic acid, tartaric acid, succinic acid, and citric acid	Narina et al. (2019), Katsayal et al. (2019).
Leaves	Luteolin 7-o-glycosides, luteolin, apigenin, isorientin, orientin, vitexin, caffeic acid, limonene, naringin, Caryophyllene, p-cymene, ß-sitosterol, vitexin, isovitexin, orientin, isoorientin and vitamin C	Escalona-Arranz et al. (2010), Bhatia et al. (1966), El-Siddig (2006).

(2014) evaluated various physicochemical, antioxidant and antimicrobial properties of rich fibre powder extracted from the tamarind pulp. Authors urged that fibre powder can be utilized during food processing as a natural preservative due to the presence of natural antioxidants (phenols and flavonoids) and antimicrobial compounds in it (Table 16.1).

16.4 Antioxidant-Mediated Biological Activities of *T. indica* and Its Mechanism of Action

Free radicals are the short-lived reactive molecules possessing unpaired electrons. Depending upon its site of production and concentration, these reactive molecules may react with cellular proteins and macromolecules and modify several cellular proteins, lipids, DNA and cellular signal transduction pathway. Both enzymatic and nonenzymatic antioxidants have different mechanism of action towards these free radicals. The working mechanism of enzymatic antioxidants includes breakdown and removal of free radicals while nonenzymatic antioxidants perform its action by directly breaking the free radical chain reactions. All natural antioxidants fall under the category of nonenzymatic antioxidants. Natural antioxidant compounds have loads of positive biological effects towards health promotion. Antioxidant-mediated biological role of tamarind includes antinematodal, anticancer, antimicrobial, molluscicidal, antifungal, antidiabetic, cytotoxic, antiviral and anti-inflammatory (Katsayal et al. 2019). Atawodi and Mubarak (2015) from their experiment reported an in vivo hepatoprotective and nephroprotective effect of different parts of tamarind attributed to its antioxidant potential. Fruit pulp extract of tamarind caused lowering in the level of non-HDL cholesterol, serum total cholesterol and triglyceride, again, an increase in high-density lipoprotein levels during an in vitro experiment performed on hypercholesterolemic hamster representative of its potential in minimizing the threat of atherosclerosis in humans (Martinello et al. 2006). Antioxidant-mediated ameliorative effect of seeds of the extracts of *Tamarindus indica* on chemically induced nephrotoxicity and renal cell carcinoma has been well explained by Vargas-Olvera et al. (2012). Various polyphenolic compounds in the seed extract have antioxidant enzyme induction as well as cancer signalling pathway blockage properties. Studies have shown that intake of antioxidants from natural sources has advantageous effect on cardiovascular system. Fruit extract of tamarind exhibits hypocholesterolemic and antioxidant properties. It increases the expression of low-density lipoprotein (LDL) receptor gene, ABCG5 and Apo-A1, and decreases the expression of microsomal triglyceride protein (MTP) coding gene and 3-hydroxy-3-methylglutaryl-CoA (HMG-CoA) reductase in the liver. In this way it prevents triglyceride accumulation in liver by increasing cholesterol excretion and intake of LDL-cholesterol from tangential tissues and lowering cholesterol biosynthesis. It prevents atherosclerosis by preventing LDL-cholesterol oxidative damage (Lim et al. 2013). Epicatechin, a flavonoid compound present in seed and fruit of tamarind, shows hypolipidemic effect by lowering triglyceride level (Landi Librandi et al. 2007). The antioxidant activity is mostly associated with the presence of a diverse group of phenolic compounds. In Tamarind, phenols are the most dominantly found natural antioxidant. These compounds act as hydrogen donors or metal ion chelators by inhibiting the oxidation of low-density lipoprotein (LDL). Phenolic compounds inactivate free radicals by transferring hydrogen molecules from its hydroxyl groups. It maintains a shielding role against various neurodegenerative diseases such as cancers and cardiovascular disease (Menezes et al. 2016). Alpha-tocopherol (vitamin E) is a potential lipid-soluble antioxidant found in the fruit of tamarind. It functions by chain breaking during reactive species mediated membrane lipid peroxidation. Tocopherol reacts with lipid peroxyl radical and forms a stable product tocopheroxyl radical that is inadequately reactive to initiate membrane lipid peroxidation by its own (Nimse and Pal 2015). Ascorbic acid (vitamin C), a hydrosoluble antioxidant mainly present in fruit pulp, is another free radical scavenger. It acts by giving away an electron to the lipid radical itself changing to ascorbate radical and thereby terminating the lipid peroxidation. The resultant ascorbate radical is feebly reactive and changes to ascorbate by reductase-dependent nicotinamide adenine dinucleotide (NADH) or nicotinamide adenine dinucleotide phosphate (NADPH). Alternatively ascorbate radical can undergo pH-dependent disproportionate reaction forming one molecule of dehydroascorbate and one molecule of ascorbate. The former does not have antioxidant property and hence it is transformed back to ascorbate by accepting two more electrons. Flavonoids are another group of compounds known for its antioxidative property. Free radical can be interfered by flavonoids through different mechanisms. One way out is the direct scavenging of free radicals in which flavonoids tend to stabilize the reactive species by reacting with them and thus making them less reactive. Radicals are made inactive because of highly reactive hydroxyl group of flavonoids. Second mechanism includes nitric oxide (NO) scavenging. Although a minimal production of NO is significant for maintaining proper dilation of blood vessel, overinduction can cause oxidative damage. At high concentration, NO tends to react with the free radicals yielding the highly destructive peroxynitrite. Peroxynitrite oxidizes LDLs; as a consequence it causes irreversible damage to the cell membrane. Flavonoids have the potential to scavenge these free radicals, resulting in less damage (Nimse and Pal 2015) (Table 16.2).

16.5 Health Benefits

Tamarind products are frequently used as health remedies right the way through Asian subcontinent, Africa and the America since time immemorial (El-Siddig 2006). The entire tree has tremendous medicinal importance that has been utilized in traditional African medicine and Indian Ayurvedic medicine (Jayaweera 1981; Parrotta 1990). Tamarind fruit is used as a blood tonic, digestive aid, expectorant, laxative and carminative (Komutarin et al. 2004). The laxative characteristic of the pulp is due to the presence of high amounts of tartaric acids, malic acid and potassium acid tartrate (Irvine 1961). The pulp unaided or in amalgamation with spices or camphor, milk, lime juice, dates and honey is used as carminative and during digestive disorders. It is also used as a remedy for bile disorders, febrile conditions and biliousness. Tamarind is also utilized for the handling of mild malarial fever (Timyan 1996). The fruits have molluscicidal, anti-bacterial and anti-fungal properties as well (Guerin and Reveillere 1984; Ray and Majumdar 1976). Antibacterial effect is due to the presence of a compound called lupeol (Al-Fatimi et al. 2007). Tamarindienal, a compound isolated from the fruit, exhibits antifungal activity (Imbabi et al. 1992; Imbabi and Abu-Al-Futuh 1992). Anti-inflammatory properties of tamarind pulp have also been well reported (Rimbau et al. 1999). Tamarind pulp extract is used to cure malarial fever and alleviate sunstroke. Pulp is used to treat skin infection and intestinal ailments. Moreover, juice extracted from pulp is used as a gargle to take care of sore throats.

Tamarind seeds are known for its antidiabetic properties (Maiti et al. 2004; Rama Rao 1975). Seeds are used in the treatment of bladder stones, ulcers and dysentery (Rama Rao 1975). Antiobesity effect of seed is due to the presence of procyanidin (Kumar and Bhattacharya 2008). The glucosyl transferase inhibitor, which is a compound obtained from seed husks, was reported to exhibit antidental caries effect in a report claimed by Tamura et al. (1996). It is also used against snake bite in India. Antivenom nature of tamarind has been studied and found that the seed extracts possess potential to inhibit protease, 5′-nucleotidase phospholipase, hyaluronidase and l-amino acid oxidase enzyme activities of venom in dosage-dependent mode (Ushanandini et al. 2006).

The boiled or dried flowers and leaves of tamarind are used as poultices for swollen joints, boils and sprains. Extracts and lotions prepared from leaves and flowers are used in treating jaundice, dysentery, haemorrhoids, erysipelas and as antiseptics, vermifuges and conjunctivitis. During coughs, urinary troubles, liver

Table 16.2 Antioxidant-mediated biological activities of *Tamarindus indica*

Compound name	Various parts	Biological effect	References
Methyl 3,4-dihydroxybenzoate	Seed coat	Anticancer, spasmolytic,	Kuru (2014), Tsuda et al. (1994)
3,4-dihydroxyphenyl acetate	Seed coat	Antimicrobial, spasmolytic	Tsuda et al. (1994), Kuru (2014)
Vitamin C	Fruit pulp	Antioxidant, immune stimulant	Kuru (2014), Meena et al. (2018), De Caluwé et al. (2010)
2-hydroxy-3′, 4′-dihydroxyacetophenone	Seed coat	Anticancer, spasmolytic	Escalona-Arranz et al. (2010), Tsuda et al. (1994), Kuru (2014)
Catechin	Pulp	Antioxidant	Kuru (2014), Bhadoriya et al. (2011)
Taxifolin	Pericarp, pulp	Antioxidant	Bhadoriya et al. (2011)
Succinic acid	Pulp	Antioxidant	Bhadoriya et al. (2011)
Apigenin	Pulp	Antioxidant, anti-inflammatory	Bhadoriya et al. (2011)
Tannins	Pulp	Antimicrobial, Antiulcers	Kuru (2014), Meena et al. (2018), Gupta et al. (2014)
Tartaric acid	Leaves, pulp	Antioxidant, antimicrobial, laxative	Meena et al. (2018), Adeniyi et al. (2017)
Terpenoids	Pulp	Anti-inflammatory, antimicrobial	Iskandar et al. (2017), Gupta et al. (2014)
Procyanidin B_2, dimer, trimer	Pulp, leaves, pericarp	Anticancer, antiulcers	Bhadoriya et al. (2011), Kuru (2014)
Orientin	Leaves	Antioxidant	Meena et al. (2018)
Isoorientin	Leaves	Antioxidant	Meena et al. (2018)
Oxalic acid	Leaves	Antioxidant, anticoagulant, allelochemical,	Meena et al. (2018)
Vitexin	Leaves	Antioxidant	Meena et al. (2018)
Isovitexin	Leaves	Antioxidant	Meena et al. (2018)
Naringenin	Leaves	Antioxidant	Meena et al. (2018)
Citric acid	Leaves, pulp	Antioxidant, anti-inflammatory	Sairah et al. (2014), Meena et al. (2018), Bhadoriya et al. (2011)
Malic acid	Pulp, leaves	Antioxidant, laxative,	Sairah et al. (2014), Bhadoriya et al. (2011), Meena et al. (2018)
Epicatechin	Pulp, seed, pericarp	Anticancer, antioxidant, antiulcer,	Tsuda et al. (1994), Kuru (2014), Adeniyi et al. (2017), Bhadoriya et al. (2011)

Source: Katsayal et al. (2019)

Table 16.3 Medicinal uses of different parts of *Tamarindus indica*

Disorder/medicinal use	Parts used	Reference
Laxative	Pulp, leaf, bark	Komutarin et al. (2004), Bhat et al. (1990), Havinga et al. (2010)
Abdominal pain	Leaf, root, bark	Havinga et al. (2010), Chhabra et al. (1987), Doughari (2006)
Wound healing	Leaf, bark	Fabiyi et al. (1993)
Diabetes	Seed	Maiti et al. (2004)
Hepatoprotective	Leaf, fruit, seed	Pimple et al. (2007)
Dysentery	Root, leaf	Bhadoriya et al. (2011), Chhabra et al. (1987)
Diarrhoea	Pulp	Bhadoriya et al. (2011)
Infertility	All arial parts	Alawa et al. (2002)
Malaria	Bark, fruit, leaf	Havinga et al. (2010)
Antivenom	Seed, leaf, root	Ushanandini et al. (2006)
Vertigo	Pulp	Havinga et al. (2010)
Anti-inflammatory	Pulp	Rimbau et al. (1999)
Mumps	Leaf	Havinga et al. (2010)
Fever	Pulp, bark, leaf	Havinga et al. (2010)
Ear ache	Leaf	Havinga et al. (2010)
Scurvy	Fruit pulp	Havinga et al. (2010)
Measles	Pods, leaves	Havinga et al. (2010)

ailments, fever, intestinal worms and throat infections, leaves are mixed with salt and water and consumed directly. Leaves and bark are mostly used to heal wounds when applied in the mode of a powder or decoction or as a poultice, separately or with other species. (Fabiyi et al. 1993). Bark of the tamarind tree is utilized as effective tonic, febrifuge and astringent. It is applied to relieve ulcers, sores, rushes and boils. Bark and leaves are used for wound healing, applied superficially on the spot, either in combination with other species, as a powder or poultice, alone or as a decoction (Table 16.3).

16.6 Conclusion

According to health experts, some synthetic antioxidants are carcinogenic so extensive use of such materials corresponds to health risk. Therefore nowadays people prefer more natural antioxidants over synthetic. Tamarind is one such easily available fruit that serves as a natural source of antioxidants. It has tremendous contribution towards traditional health care system and its tremendous potential can be used more extensively in developing modern-day drugs. Therefore, further investigations and research work should be carried out about its antioxidant and biochemical potential with the aid of modern techniques for finding out the enormous scope hidden within this majestic plant *Tamarindus indica*.

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17 Watermelon

Sangeeta, Gulzar Ahmad Nayik, and Khalid Muzaffar

Abstract

Watermelon is an excellent refreshing and thirst-quenching fruit. In addition to its juicy, crisp and sweet delicacy in taste, it is also a well renowned source of various phytochemicals having antioxidant and other health beneficial potential. Not only the flesh and juice of watermelon fruit, but also its other parts, such as seed, rind and pomace, are being reported to have appreciable antioxidant and disease preventing potential. This chapter reviews the phytochemicals (antioxidant), their characteristics, biological activity and other potential health beneficial properties of watermelon fruit and its by-products. The chapter tabulates the antioxidant compounds, their antioxidant activity and disease prevention as reported by various studies. The watermelon fruit, its by-products and extract have been reported to exhibit various therapeutic and medicinal health attributes and could be proved beneficial if consumed with regular diet in a proper amount.

Keywords

Watermelon · Phytochemicals · Antioxidant activity · Health beneficial properties · Therapeutic properties

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17.1 Introduction

Botanical Name: *Citrullus lanatus* (Thunb.) Matsum & Nakai
Family: Cucurbitaceae
Synonym: *C. citrullus* (L.) Karst., *C. edulis* Spach., *C. vulgaris, Colocynthis citrullus* (L.) O. Kuntze/Fritsch, *Cucubertia citrullus* L.
Common Name: English: Watermelon; India: Tarbnj Jamaika; Hindi: तरबूज़ (Tarbooz); Urdu: Tarbooz

Watermelon is an important horticultural crop grown for their fleshy fruit having juicy, crisp, delicacy in taste, sweet, refreshing and thirst quenching (high water) quality attributes along with appreciable nutritional health benefits (Romdhane et al. 2017; Maoto et al. 2019). Watermelon is ranked among the top five fruits worldwide (Gao et al. 2020). The origin of watermelon is not clear, but as per the reported data, it is believed to have originated from the tropical and subtropical regions of Africa and later on widely distributed throughout the world (Zhang et al. 2011). Seeded and seedless genotypes of watermelon with over a thousand varieties are present (Perkins-Veazie et al. 2012). Mature watermelon is mainly enjoyed as such after peeling or in the form of juice, and other parts are also used occasionally. It is used for making summer squash from immature fruit and pickles from rind, and the seeds are also edible and nutritionally important. Other uses of watermelon are production of alcoholic drink by fermentation of juice and as livestock feed. Commercialization and storage of watermelon juice are difficult because of its almost neutral pH, and so it is often mixed with other high acidic juices. Various novel thermal and non-thermal treatments should be given for quality improvement, shelf life extension and reducing enzymatic browning. (Ishita and Athmaselvi 2017; Makroo et al. 2017). The requirement of watermelon fruit texture is different for different consumers as the taste and storage quality is affected substantially by the texture of fruit (Risse et al. 1990; Harker et al. 2003). Therefore, cultivation at right time with different fruit texture to meet the consumer demand is an important aspect. Watermelon is gaining popularity among consumers because of uniqueness in its refreshing flavour and highly nutritious and health beneficial effects of its different parts due to the presence of different phytochemicals (Edwards et al. 2003; Giovannucci 2002). Watermelon offers calories (6.4 g/100 g carbohydrates), water (93%), protein (high in seeds), fat (high in seeds), minerals (mainly phosphorus, iron, calcium and magnesium) and vitamins (A, B, C and E) in good amounts (Romdhane et al. 2017; Maoto et al. 2019). Watermelon has various antioxidant phytochemicals, for example, lycopene (2300–7200 μg/100 g) as a major nutrient component having antioxidant activity, citrulline, β-carotene, vitamin A and C and polyphenols in appreciable amounts (Wehner 2008). Seeds of watermelon also have various health beneficial components and are a good source of fibres; seeds contain oil having therapeutic properties. Lycopene is an important antioxidant compound present in dark and red flesh watermelon, and its amount in watermelon is higher than various other lycopene-rich fruits, such as pink grapefruit/guava, tomato and orange. The red and orange colours of watermelon are due to particular pigments such as lycopene (red), β-carotene (orange) and other carotenoids. It exhibits anti-oxidant potential with various health beneficial effects, such as anti-carcinogenic, anti-inflammatory and anti-oxidative stress (Romdhane et al. 2017; Maoto et al. 2019). As each part of the watermelon fruit has various nutritional and health beneficial components, it is important to utilize maximum of this crop to meet the mankind requirements. This chapter focuses on the nutritional and antioxidant phytochemicals present in watermelon and their health benefits.

17.1.1 History

Watermelon has a long history. According to the literature, watermelon is thought to be the native of tropical areas of Africa near Kalahari Desert (cultivated for over 4000 years in Africa) because of its wild growth throughout the area and the maximum diversity there (Naz et al. 2014; Kyriacou et al. 2018; Maoto et al. 2019). In spite of this, it is also reported in the literature that its origin is not clear or still unknown because of its primitive cultural history as was found to be known before 2000 BC. It was cultivated widely in the Nile valley as seeds and plant parts are found in Egyptian tombs (Kyriacou et al. 2018). There are also some evidence regarding North American origin of the *Citrullus* species (Compton et al. 2004). There are various theories regarding the origin of watermelon (Kyriacou et al. 2018). One theory suggested that it was derived from *C. colocynthis*, the perennial relative found wild in the archaeological sites, while another claims its domestication from *C. lanatus*, which is a wild form found in central Africa. The plant originated from the desert Kalahari in Africa and now is grown worldwide (more than 96 countries). Later on its cultivation extended towards the Arabian and Mediterranean countries and then spread to USA and Eastern Asia, as reported in the literature (Oyenuga and Fetuga 1975). Moreover, it is believed to be introduced at about 800 CE to India according to ‘Sushruta Samhita’ (written by Sushruta—the great Indian physician), mentioning its cultivation along the Indus river. It then spread to China at around 900 CE and afterwards in the 1500s, it extended towards Southeast Asia, Japan, Europe and USA (Kyriacou et al. 2018). The likely antecedent of watermelon is considered to be *C. colocynthis*, in spite of its small seeds and bitter fruit, because of its morphological similarity to *C. lanatus*. However, the probable watermelon ancestor was also believed to be *C. lanatus* bitter forms. Although in southern and central Africa some of the *Citrullus* species grow wild, in India also *C. colocynthis* is found to grow in wild form. In can be considered that secondary centres of this genus diversity may be India and China (Wehner 2008).

17.1.2 Production

Worldwide watermelon is undoubtedly one among (stands second after tomato) the prominent annual kosher fruit crops. This can be clearly proved by its cultivated acreage (4.7%) and production (7.8% of the world production in terms of vegetable), together with root vegetables (Kyriacou et al. 2018). During 2009–2010, the global production of watermelon was 73,490,835 MT. The global production of watermelon (*C. lanatus*) was 118 million tonnes approximately in the year 2017, making it one among world's largest fruit crops. Moreover, there has been 25% increase in the world production of watermelon during the last 10 years (Rico et al. 2020). In watermelon production, the Asian countries (China with 23%) with two-thirds of the volume dominate the world, followed by European (13%) and Mrican (6%). The five top countries in terms of watermelon production are China with 57.65 MMT (million MT) and then Turkey with 3.90 MMT, followed by Iran with 1.9 MMT, the USA with 1.78 MMT and Egypt with 1.45 MMT production (Compton et al. 2004). The annual production of watermelon has been fluctuating for the last 10 years at around 30 million tonnes, with China being the main producer having a share of 70–75% (year 2005; 2009–2010) of the total production, while it is 4% for turkey (2009–2010). The USA watermelon crop in the year 2002 crossed 326 million dollars and the annual world value for it exceeded $15 billion as per the rough estimation (Compton et al. 2004; Kumar and Kulkarni 2018). More than 1200 varieties of watermelon are grown worldwide and its global consumption is higher than any other crop of its family (cucurbit) (Zohary and Hopf 2000).

India stands at 26th position in terms of watermelon production; the area under its cultivation and the production volumes have been increasing over the years (Fakir and Waghmare 2017). The total production area under watermelons in the year 2000 was 20,000 ha, while 255,000 MT was the production. The area under the production of watermelon during 2016–2017 was 95,520 ha with 2,362,160 MT production. In India, the leading states in terms of area under watermelon production in the year 2016–2017 were West Bengal (16,540 ha area under production), followed by Uttar Pradesh (13,020 ha), Karnataka and Odisha (11,730 ha each), Andhra Pradesh (8520 ha) and Tamil Nadu (6420 ha), whereas in terms of production, leading states were Uttar Pradesh with 586,610 MT production, followed by Karnataka (388,550 MT), West Bengal (230,100 MT), Odisha (226,640 MT), Andhra Pradesh (196,960 MT) and Tamil Nadu (175,150 MT) (Kumar and Kulkarni 2018). During 2010–2011, India exported 12,572.56 tonnes of watermelon, worth ₹ 151,087,769. The major part of the exports is for the UAE, Bangladesh and Nepal. Netherlands, Maldives, Germany, Canada, the United Kingdom, Bahrain, Saudi Arabia and Oman are also the other importers of Indian watermelon. Globally, Mexico is the biggest exporter and exports the highest volume of watermelons (Varmudy 2012).

17.1.3 Botanical Description

The watermelon (*C. lanatus*) is a vining annual monoecious plant, which is thin, grooved vine covered with tiny hairs. It belongs to the Cucurbitaceae family of flowering plants. It is a long trailing and scrambling herb with frequently and easily extending stems of more than 5–6 m in length with 5–20 cm long; softly pubescent (hairy) leaves, trifid, with bipinnatifid segments, lobed (obtuse-round/obovate-oblong); and strong bifid tendrils. The leaves are very smooth from upper side and very rough on reverse side with strongly marked nerves. The plant produces pale yellow coloured small solitary masculine flower, which is feminine and pollinated by insects. It opens for 1 day and may abort if inadequately pollinated or fruit load is excessive. In the axils of the leaves, flowers are borne, and feminine flowers give rise to large spherical to oblong watermelon fruits with varying weight (3–25 kg). The shape of the fruit (round, oval or cylindrical), size (range from 1 to 3 kg 'icebox' type to >25 kg) and surface colour depend on the variety. The shapes of watermelon fruits vary from oblong to round or elongated (blocky or pointed ends). The fruit of watermelon belongs to a special category known as 'pepo' by botanist—a fleshy fruit or berry protected by a thick (1–4 cm) rind that is leathery (exocarp) due to surface wax (increase with maturity) and fleshy centre (mesocarp and endocarp). Watermelon fruit is smooth with green colour exterior rind (light to dark) having striped, solid and marbled and measures 30 × 45 cm^2 (Matthew 1991). The red colour flesh (due to lycopene) is usually common, but yellow (β-carotene and xanthophylls), orange or white colour flesh is also produced by some cultivars with numerous seeds to seedless varieties. Flesh texture (stringy or fibrous) as well as sugar content also differs in different cultivars (Rubatzky and Yamaguchi 1997).

17.2 Antioxidant and Other Health Beneficial Aspects of Fruit, Juice, Seed, Peel Waste and Its Products

Phytochemicals present in watermelon are mainly lycopene and β-carotene as pigments; amino acids, specifically citrulline first extracted from watermelon (converted to arginine later on); phenolic compounds; and vitamins (water-soluble B, C and fat-soluble A, E), which are the main contributors of antioxidant property and other disease preventing health benefits (Kim et al. 2014). Apart from these, other important nutrients are also present in watermelon, such as minerals (K, Mg, K, Mn, Zn, Fe etc.), proteins and carbohydrates with a very low or negligible amount of sodium and cholesterol (Perkins-Veazie et al. 2007; Tlili et al. 2011). Flesh of fruit contains sugars, such as saccharose, dextrose, levulose, invert sugar, along with other phytochemicals, such as citrulline, lycopene and carotene. Watermelon juice has moisture content (91.25–93.12%), total solids (6.3–6.88%), acidity (0.03–0.13%), soluble solids (6.4–9.0 g/100 g), reducing sugars (3.58–5.52%), total sugars (4.80–7.76%), non-reducing sugars (1.11–1.40%) and ascorbic acid (4.09–5.2 mg/100 g) (Fila et al. 2013; Yau et al. 2010). Nutrient content of watermelon juice varies, which may be due to variation in cultivar, type, geographical area and so on. The skin of fruit (exocarp) has appreciable concentration of antioxidants (phenolics), fixed oil and arachidic acid, and copper is present in traces. The seeds of watermelon fruit have oil containing glycerides of linoleic acid up to 50% with glucoside-saponin (cucurbitacin) as the active principle component (Parmar and Kar 2009). Most of the studies show that phytochemicals exhibiting antioxidant and other health benefits are present in different sections of the watermelon fruit (peel, rind, flesh and seed) and in varying proportions. The amounts of phytochemical (lycopene, carotenoids, citrulline, polyphenols etc.) and the

Table 17.1 Average range of antioxidant components with their antioxidant activities present within the different sections of watermelon fruit (Blossomend, Stemend, Heart, Peripheral)

Components	Amount
(A) Antioxidant	
Lycopene	61.5–75.8 (mg/kg FW)
Total phenolic	102.2–122.3 (mg GAE/kg FW)
Flavonoids	131.7–157.0 (mg RE/kg FW)
Citrulline	3.9–28.5 (mg/100 g DW)
Ascorbic acid	63.8–95.6 (mg/kg FW)
Dehydroascorbic acid	89.7–105.01 (mg/kg FW)
Total vitamin C	165.9–187.7 (mg/kg FW)
(B) Antioxidant activity (FW)	
Trolox equivalent antioxidant capacity (TEAC) assay (μmol Trolox/100 g)	
HAA	193.2–281.5 (ABTS decolouration method)
LAA	219.6–257.8 (ABTS decolouration method)
TAC	40.13–84.05 (cupric reducing antioxidant capacity)
Ferric reducing antioxidant power (FRAP) assay	
HAA	22.60–30.20 (mM FRAP/g FW)
LAA	29.30–37.40 (mM FRAP/g FW)
Free radical scavenging activity (DPPH%)	29.11 ± 1.91 (Juice) 57.0 ± 3.22 (Lycopene extract)
TAC (β-carotene %)	49.0 ± 3.10 (Juice); 73.0 ± 3.20 (lycopene extract)

Sources: Modified from Tlili et al. (2011), Choudhary et al. (2015) and Naz et al. (2013)
Abbreviations: *GAE* Gallic acid equivalent, *HAA* hydrophilic antioxidant activities, *LAA* lipophilic antioxidant activities, *TAC* total antioxidant capacity, *FW* fresh weight basis, *DW* dry weight basis, *RE* Rutin equivalent

antioxidant activity exhibited by them vary depending upon the cultivars, type and sampling area. Apart from all these, the variation in antioxidant activity may also be due to variation in sampling, extraction and evaluation methods (Leskovar et al. 2004; Tlili et al. 2011; Maoto et al. 2019). The amount of antioxidants and their antioxidant activity in watermelon as reported by some researchers are given in Table 17.1. Processing of watermelon fruits yields 41.5–60% juice, 31–49.6% rind and 8.9–23.6% pomace (Sogi 2003; Maoto et al. 2019). Phytochemicals present in different parts of watermelon fruits and its part, their antioxidant activities, associated health benefits and possible uses are described in the following sections.

17.2.1 Fruit Flesh and Juice

Higher concentration of lycopene in watermelon fruit, even greater than that of tomato, proves its importance as a valuable lycopene source. Watermelon may be used in diet as a bioavailable source of lycopene (Edwards et al. 2003). Not only lycopene, but other important antioxidants are also present in watermelon flesh and juice, such as citrulline, β-carotene and polyphenols. The antioxidants and other possible health beneficial aspects of watermelon juice and flesh are as follows:

(1) Owing to natural antioxidants, it helps in reducing oxidative stress (carbon tetrachloride induced) and liver damage (hepatic toxicity) by protecting the hepatic enzyme activity and combating the reactive oxygen species (Maoto et al. 2019). (2) Polyphenols in combination with flavonoids, carotene and carotenoids as well as triterpenoids exhibit antioxidant and anti-inflammatory effects, thus making it a health promoter. (3) Citrulline present is about 250 mg/cup serving, which when absorbed in body plays an important role in nitric oxide cycle by converting into arginine. It helps the body in improving flow of blood and in turn the cardiovascular system by providing enough arginine, especially when body is not able to synthesize sufficient arginine. In this way, it helps in blood vessel relaxation, improves flow of blood giving vasodilatation effect and in turn lowers the blood pressure. Additionally, erectile dysfunction can be improved due to high citrulline content. Formation of polyarginine peptides during citrulline conversion to arginine helps in reducing fat accumulation (adipose tissue) by inhibiting the tissue non-specific alkaline phosphatase enzyme (TNAP) (involved in adipocyte fat accumulation). (4) A triterpenoid in watermelon called cucurbitacin E is a phytonutrient having anti-inflammatory properties. The activity of enzyme cyclooxygenase has been shown to be blocked by this phytonutrient and in turn involved in the neutralization of reactive nitrogen species. (5) It is used for cleaning of kidneys and urinary tract and is used in Chinese traditional medicine for relive from thrust, scanty urination, hepatitis treatment and infections of urinary tract. (6) It is a good source of various nutrients as well as antioxidants, such as citrulline, lycopene, vitamin C, β-carotene and vitamin A as explained above (Collins et al. 2007; Rimando and Perkins-Veazie 2005; Charoensiri et al. 2009; Parmar and Kar 2009; Poduri et al. 2013; Abdelwahab et al. 2011). (7) Watermelon juice is used in the treatment of typhus fever as an antiseptic. (8) Watermelon juice, due to its low sodium (0.0–0.001), saturated fat, cholesterol (0.00–0.01 mg/100 g) and a high level of antioxidants, can be used as an effective remedy against weight loss as evidenced by various studies (Maoto et al. 2019).

The nutraceutical components and antioxidant activity in the extract of watermelon can be increased by the hydrothermal treatment; catechol and its derivatives (new phenolic compounds in watermelon) were also identified in hydrothermal extracts (Kim et al. 2014). Freezing increases the bioavailability of lycopene as plasma concentrations (lycopene) are elevated from 100% to 200% by lycopene consumption per day (18–20 mg) from watermelon juice (fresh frozen). Heat treatment does not have any significant effect on lycopene absorption from watermelon juice (Edwards et al. 2003). Various clinical trials exhibit that measured human plasma citrulline levels in subjects tested increased with increase in consumption of watermelon juice per day (Perkins-Veazie et al. 2007). Therefore, watermelon juice can be used as a medicinal alternative if used properly. The watermelon plant is considered as a medicinal plant because of the presence of health beneficial constituents as reported in the literature (Said 2014). The lycopene and other antioxidants due to their health beneficial effects make watermelon juice a pre-eminent option for value added food products and in turn also increase its utilization (Kim et al. 2014).

17.2.2 Seed

Various important phytochemicals with antioxidant and other health beneficial properties present in watermelon seeds are lycopene, riboflavin, β-carotene, polyphenolic compounds, xanthophylls, vitamin C; protein globulin, albumin, glutelin; thiamine; glycoprotein vicilin; amino acids arginine, isoleucine, leucine and so on (Wani et al. 2011; Olamide et al. 2011; Yadav et al. 2011). The watermelon seed contains considerable amounts of total phenols (1494 mg GAE/100 g 5416 mg GAE/100 g) in a wide range depending upon the variety, growing conditions and the sampling procedure (Tabiri et al. 2016). The lower value of phenols in the watermelon seed reported is 969.3 mg GAE/100 g (Joshi and Jain 2012). The antioxidant activity of watermelon seeds in terms of DPPH (2,2-diphenyl-1-picrylhydrazyl) scavenging ability varies from 56.93% to 94.46% and the free radical scavenging activity ranges from 82.59 to 130.29 μM Trolox/g (Oseni and Okoye 2013; Tabiri et al. 2016). Watermelon seeds (55% oil DW) contain linoleic acid, which is the polyunsaturated omega-6 fatty acid (one of the essential fatty acids), and the amount is about 50–60% of the total fatty acids present along with 15% oleic acid and comparatively less stearic and palmitic acids (Logaraj 2011). Thus, 600 calories and 79% of Recommended Dietary Allowance(RDA) of fat are provided by the watermelon seed. The estimated values of protein, fat, water, energy, carbohydrate, calcium, phosphorous, iron, thiamin, riboflavin, niacin and folate content of dried seeds (without shell) of watermelon are 28.3 g, 47.4 g, 5.1 g, 2340 kJ (557 kcal), 15.3 g, 54 mg, 755 mg, 7.3 mg, 0.19 mg, 0.15 mg, 3.55 mg, 58 μg per 100 g, respectively, of dried seed sample. Watermelon seeds contain several B complex vitamins (3.8 mg/31 g of seed) equivalent to 19% of the total daily need. In terms of minerals, Ca, Fe, Mg, Mn and Zn are the major elements of watermelon seeds (Tabiri et al. 2016).

The essential fatty acid, that is, linoleic acid, a major seed oil part, helps in decreasing both the body cholesterol and the hypertension problem, thus promoting good health if consumed in moderate concentrations, but it is proved to be harmful at the high level. The involvement of these acids is found in oxygen transportation to blood, production of energy, synthesis of haemoglobin, growth and division of cells and neural functioning of body due to their abundance nervous system. Various dysregulations such as loss of chronobiological control, blunt response of cognitive sense and weak immunity are due to fat deficiency, mainly in infants. The polyunsaturated fatty acids are involved in releasing specific factors, hormones and cytokines and in turn neuronal membrane fluidity (Yehuda et al. 2000). The ample polyunsaturated fatty acid in the seed of watermelon is the basic reason behind these health benefits and the seed oil is also attracting attention in the treatment of complications related to cardiovascular system and carcinogenic effect (Logaraj 2011). In addition to composite amino acid (glutamic acid, tryptophan and lysine), arginine is also present, which is involved in nitric oxide production and further exhibits various antioxidant and other bioactive properties, such as blood pressure regulation and control of cardiac disease. Watermelon seeds (at epithelial cells of glands) have diuretic, laxative effects, antihelminthetic and anticarcinogenic effects.

Additionally, seeds have anti-inflammatory and dilating capillary (regulating blood pressure) effects, particularly in hypertension related to post-menopausal obesity (Logaraj 2011). Thus, watermelon seeds if consumed fresh or added in food products can provide medicinal, economic and health benefits due to the presence of antioxidants exhibiting antioxidant activity in appreciable amounts (Alka et al. 2018). Thus, they have a great potential if incorporated in value-added products: cakes, cookies, as food grade oil, roasted (tea or soups) and so on. They are proved to be helpful in fulfilling the nutritional requirements and combating with various degenerative diseases.

17.2.3 Peel Waste and Its Products

The edible portion of watermelon fruits is only 50%, and other 50% is in the form of rind (>35%) and peel (15%) that goes waste. Watermelon is mainly used as such or for the production of fruit mix, juices, fruit cocktails and nectars; leaves, rind and seeds go as waste (Ahmed 1996). Utilization of seeds and their antioxidant properties have been discussed already in the previous section. The major by-product of watermelon processing is 'rind', which has appreciable amounts of most of the phytochemicals, such as citrulline more than that in flesh, lycopene, flavonoids, phenolic acids, carotenoids and many other important antioxidants. Additionally, dietary fibre and minerals are also present in good amounts. Antioxidant activity in terms of free radical scavenging assay (DPPH) and ferric reducing antioxidant potential assay (FRAP) (different extraction solvent—water, methanol, ethanol and acetone) of rind powders from red and yellow colour watermelon produced by drying at 40 °C and 60 °C (oven) and freeze drying ranged from 23.49% to 84.88% and 12.90% to 85.28% ascorbic acid inhibition and 319.43–700.18 and 304.32–768.66 mg FE/100 g (DW), respectively (Ho et al. 2018). Hot air-dried rind powder has higher antioxidant activity as compared to freeze dried. Total phenols ranged from 127.93 to 218.39 mg GAE/100 g for red colour variety and from 111.00 to 213.21 mg GAE/100 g for yellow colour variety watermelon rind powder. Total flavonoid content of red and yellow fleshed watermelon rind powders extracted using different solvents ranged from 13.95 to 193.43 and 14.24 to 171.85 mg CEQ/100 g, respectively. All the values observed were on dry weight basis (Ho et al. 2018). Watermelon rind powder (6–12%) as a partial wheat flour replacement in pan bread resulted in increase in phenolic content (18.85–33.04 mg GAE/100 g on DW) and flavanoids (3,9-fold compared to wheat flour pan bread) with increasing level of rind powder (Badr 2015). The antioxidant activity of pan bread with different levels of rind powder (3.10–3.90 mmol Trolox/kg) is higher than that of pan bread having wheat flour without rind powder (2.95 mmol Trolox/kg). Increase in shelf life is also reported in pan bread with rind powder (10 days) in comparison with pan bread without rind powder (6 days), which may be due to improved antioxidant potential (Badr 2015). The phenolic content and the antioxidant activity of watermelon samples (flesh, green rind and white rind) were enhanced significantly by the hydrothermal treatment (Kim et al.

2014). Watermelon pomace has high lycopene concentration as compared to the juice, that is, 20–24 mg/100 g lycopene in watermelon pomace, which is much higher than juice (Oberoi and Sogi 2017a). The extraction of water insoluble pigment of watermelon tissue (centrifugation) yielded 8.89% watermelon pulp in the form of pallet, which can be further used for pigment extraction. The citrulline and other phytochemicals having antioxidant effects present in watermelon rinds protect the body from free radical damage if consumed in sufficient amounts. Arginine and its precursor citrulline play an important role in the immune response during inflammation and sepsis (Rimando and Perkins-Veazie 2005).

Owing to its antioxidants and health beneficial phytochemicals, the utilization of rind in the form of value-added products, as well as extraction of medicinal components, is gaining attention. Traditionally, it has been utilized in the form of pickle, pectin source, preserved and cooked vegetable, etc. Rind (after drying and incineration) has been used traditionally in China for the treatment of aphthous stomatitis (mouth sore). Nowadays, it is used in making products with value addition, such as bakery products (bread, cakes), rind powder and candy; however, it is important to develop the products that fulfil the customer demand in terms of sensory and nutritional aspects with effective physiological attributes (Siro et al. 2008). Various studies describe its utilization in different forms, such as dried and dehydrated products like rind powder and candy. According to a study, watermelon rind powder addition in various bakery products resulted in improved rheological properties with increasing stability and better product conservation (El-Badry et al. 2014).

The watermelon by-products, such as peel, rind, seeds and pomace, as discussed above have impressive percentage of phytochemicals with potential antioxidant attributes and their concentration can also be enhanced by various treatments (Perkins-Veazie et al. 2006, 2007). After proper processing and utilization in appropriate way, it can be made possible to get all the health benefits associated with watermelon fruit and its by-products effectively.

17.3 Chemical Compound(s) Present in Watermelon Responsible for Antioxidant Properties and the Pathways Involved in Their Biological Activities

Watermelon is a tropical quintessential fruit containing various phytochemicals, namely, vitamins, minerals, pigments (lycopene, β-carotene), amino acid (citrulline, arginine), phenolics and flavonoids, which are of great importance with reported health benefits and disease preventing properties (Choudhary et al. 2015). Different sugars present in watermelon are fructose (30–50%), sucrose and glucose (20–40%), which in combination give a particular sweet taste (Bianchi et al. 2018). Dietary intake of the antioxidant-rich food products has far-reaching effects in the maintenance and proper functioning of the body for health and well-being. This is because of their potential of inhibiting or scavenging free radicals, reactive oxygen/nitrogen species and many more toxics via different mechanisms explained later in this section and shown in Fig. 17.1. Antioxidants inhibit or neutralize free radicals by electron transfer and electron addition by hydrogen atom transfer (at prevention, interception and repair levels) (Romdhane et al. 2017; Kulczynski et al. 2017). Phytochemicals exhibit antioxidant, anti-inflammatory and hypotensive properties; thus, if they are included in the diet, they have positive effects on the human body. Various body conditions such as hypertension, high level of cholesterol, diabetes, obesity, as well as heredity, age and race, are the factors involved in the acceleration of diseases formation. Unhealthy lifestyle and poor diet are also the major factors that enhance the free radical formation. It is believed that improving body's antioxidant status by adequate inclusion of these phytochemicals in diet is pivotal to impede the damaging effects resulting from free radical and discourage the disease and its formation successively (Kulczynski et al. 2017).

The phytochemicals found in watermelon, their antioxidant properties and biological pathway are explained in this section.

17.3.1 Lycopene

Watermelon in terms of lycopene source is one among the handful of lycopene-rich food. The average lycopene of watermelon is about 40% higher than that of the raw tomato and it stands fifth among the major lycopene contributors in the US diet (Chug-Ahuja et al. 1993; Edwards et al. 2003). Lycopene (C40H56) is the principal pigment of the carotenoids naturally found in many plants and microorganisms as they can synthesize it, but it is absent in animals because of their incapability to synthesize it naturally. It is a non-provitamin A carotenoid and has about double in vitro antioxidant capacity compared to that of β-carotene (Bohm et al. 2002). It is an acyclic (linear chain) isomer of β-carotene having 13 double bonds (11 conjugated and 2 unconjugated) and possesses the highest degree of unsaturation (Soteriou et al. 2014). In natural sources like plants, most of the lycopene is in its stable form (*trans* configuration) (Fig. 17.2). In the blood serum, the crucial component is lycopene and available as an isomeric mixture having *cis* isomers as 50% of the total lycopene present. Out of the total carotenoids present, 21–43% is contributed by lycopene and much of the accumulation is in the human tissue (Elumala et al. 2013). Lycopene (polyene) under the effect of thermal energy, light, and chemical reactions undergoes *cis–trans* isomerization (Nguyen and Schwartz 1999).

Lycopene is a red colour pigment that imparts desirable colour to various fruits and vegetables, such as watermelon, tomato, red bell peppers and guava (Soteriou et al. 2014). The red colour of lycopene is due to the absorption of much of the visible spectrum of progressively longer wavelengths, which becomes possible due its conjugated carbon double bonds (higher in number). This proves as a helping hand for the electrons to transit to the higher energy states by reducing the energy required for transition. However, the oxidation of lycopene by bleaching agents or acids breaks the double bonds, resulting in cleavage into smaller molecules. Discoloration occurs as shorter molecules are not able to absorb enough light to appear colourful. Reduction of lycopene also has the similar effect as reduction diminishes

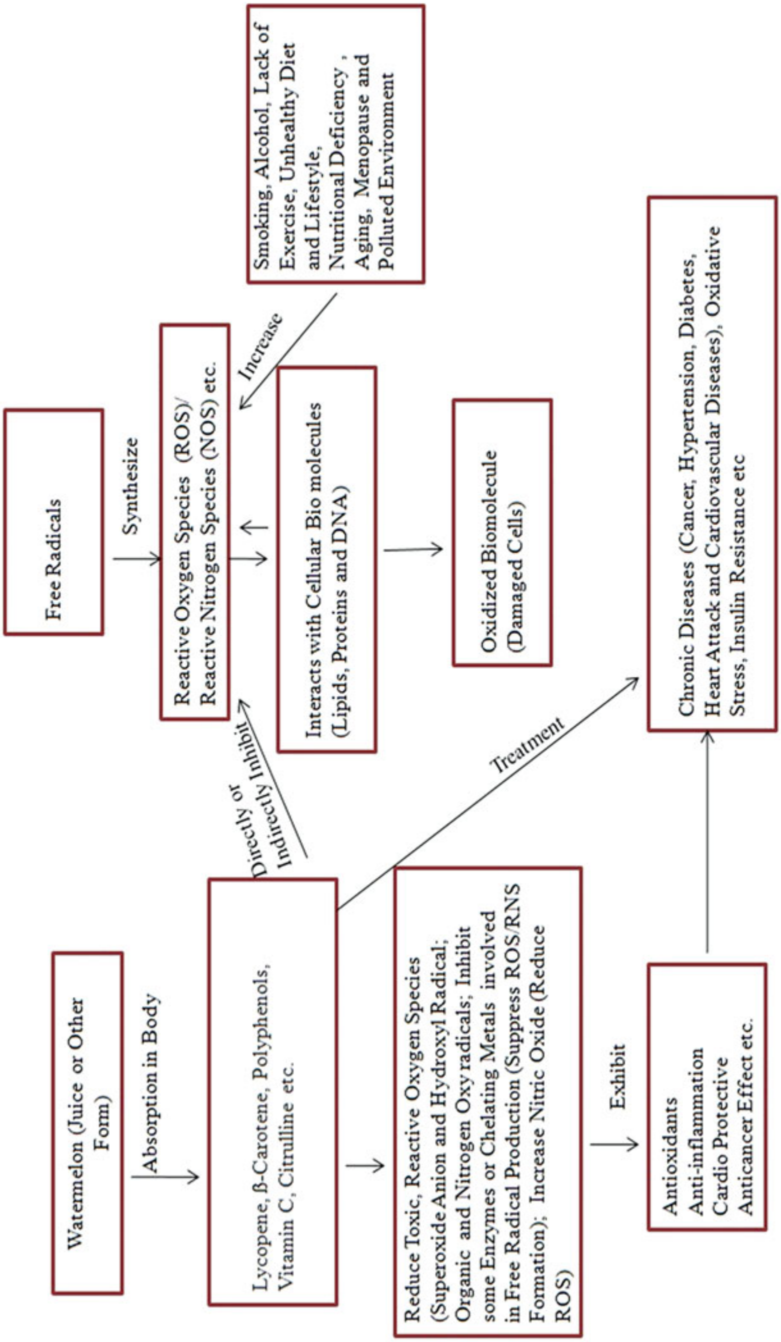

Fig. 17.1 Mechanism involved in inhibition of the disease by the action of phytochemicals. (Source: Modified from Maoto et al. 2019)

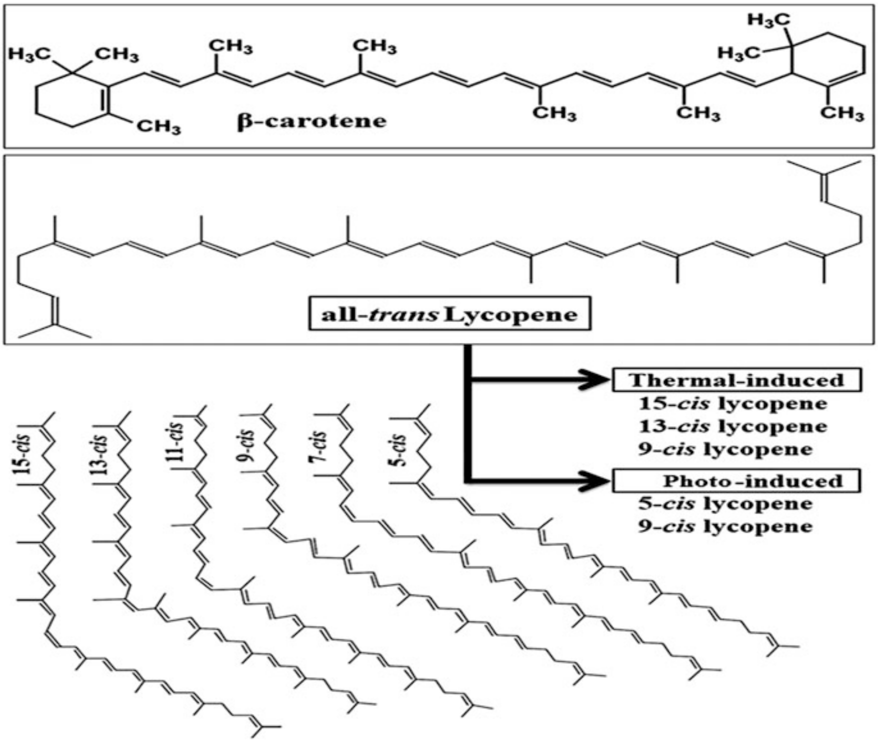

Fig. 17.2 Chemical structure of β-carotene and lycopene and thermal and photoinduced isomers of lycopene. (Source: Modified from Srivastava and Srivastava 2015 and Maoto et al. 2019)

its light absorbing capability because of the saturation of molecule (conversion of double bond to single bond) (Srivastava and Srivastava 2015). In addition to its colour-imparting property, various health beneficial effects have been recognized with its presence, thus increasing its importance manifolds. Lycopene may have shielding or defensive effects against cancers (certain type) and cardiovascular disease as suggested by some epidemiological studies (Helzlsouer et al. 1989; Burney et al. 1989; Giovannucci et al. 1995; Kohlmeier et al. 1997; Klipstein-Grobusch et al. 2000; Edwards et al. 2003).

The incorporation of lycopene in body is mainly through diet, as fruits and vegetables are the main sources of it (Castro-Lopez et al. 2017). Only 10–30% is absorbed out of the total consumed lycopene, and in developed countries 5–7 mg/day intake of lycopene has been reported (Petyaev 2016). The higher bioavailability of lycopene present in watermelon, about 60% than that of tomato (the richest source) even, makes watermelon the chief among fresh fruits and vegetables as the lycopene source (Srivastava and Srivastava 2015; Oberoi and Sogi 2017a).

Digestion process starts after the consumption of food. Owing to fat-soluble nature, the conversion of lycopene into lipid phase occurs in stomach, which gets dispersed due to the action of bile salts and pancreatic lipases (Petyaev 2016). The lycopene is then absorbed by intestinal wall (passive transport mechanism) with the help of a transporter—scavenger receptor class B type 1 protein (Kulczynski et al. 2017). After their incorporation into lipid micelles in small intestine, they get distributed in the form of chylomicrons to body's fatty tissues and organs (liver, testes, seminal vesicles and adrenal glands) eventually (Elumalai et al. 2013).

The remarkable antioxidant capacity of lycopene is due to its higher ratio to carotene (1,12) (Naz et al. 2014) as shown in Fig. 17.2. Among all carotenoids, lycopene is a strong antioxidant with effective free radical scavenging and oxygen quenching abilities (Srivastava and Srivastava 2015; Oberoi and Sogi 2017b). Its scavenging rate is twice that of β-carotene and 10 times higher than α-tocopherol in quenching ability (singlet oxygen activity) as reported by in vitro studies (Naz et al. 2014; Kulczynski et al. 2017). The natural form of lycopene is effective in restraining the damaging free radicals and inhibiting the damage of DNA and cellular membrane, thus increasing the demand of its natural form in the recent years (Kulczynski et al. 2017; Kehili et al. 2017; Kyriacou et al. 2018; Maoto et al. 2019). Lycopene has the capacity to inhibit the enzyme formation, which is used for cholesterol synthesis, and in turn decrease the lipid cholesterol level (Elumalai et al. 2013; Johary et al. 2012). Additionally, decreased lymphocyte susceptibility to oxidative stress (Riso et al. 1999; Porrini and Riso 2000), reduction in lipid peroxidation (Agarwal and Rao 1998; Bub et al. 2000), LDL (low-density lipoproteins) oxidation reduction (Agarwal and Rao 1998) and anticarcinogenic actions have been reported by numerous studies.

The role of lycopene metabolites as an antioxidant is not so much evident as that of lycopene in its intact form, especially in case of in vitro studies. However, some important antioxidant functions of lycopene metabolites are also suggested by some recent studies. The product from excentric cleavage of lycopene, that is, apo-10′-lycopenoic acid (3–10 μM), has an indirect antioxidant effect in human bronchial epithelial cells (BEAS-2B). The treatment resulted in reduction in endogenous reactive oxygen species production in dose-dependent manner and results were comparable to those of *tert*-butylhydroquinone (*t*BHQ) treated cells. The effect of apo-10-′-lycopenoic acid (3–10 μM) on oxidative damage (induced by H_2O_2) as measured by the release of lactate dehydrogenase (LDH) has also been reported. The LDH release was found to be inhibited in apo-10′-lycopenoic acid pretreated BEAS-2B cells and had comparable results to those of *t*HBQ treated cells (Lian and Wang 2008). Thus, it can be concluded from the data that generally lycopene metabolites and particularly apo-10′-lycopenoic may have the potential to possess indirect antioxidant functions (Lian and Wang 2008; Mein et al. 2008; Wang 2012).

In addition to the important antioxidant function of lycopene, there are other mechanisms also that influence its biological effect. Such mechanisms are intercellular gap junction communication, hormonal and immune system (retinoid activity), induction of phase II enzymes, interference with growth factors, cell proliferation and apoptosis (Levy et al. 1995; Johary et al. 2012).

To describe the potential pathway of lycopene in terms of its antioxidant and anticarcinogenic attributes, physical and chemical mechanisms are the major mechanisms (Elumalai et al. 2013). The physical mechanism involves the process of imparting energy to lycopene from free radicals to form excited isomerized lycopene. However, the beneficial activities of lycopene in the body depend on the cell, its site of action within cells and its molecular and physicochemical properties (Naz et al. 2014). Presence of oil in diet improves the absorption of lycopene in body because of its fat-soluble nature can clearly explain this (Johary et al. 2012). Lycopene is involved in the prevention of inflammation by reducing pro-inflammatory mediator production (Choudhary et al. 2015; Dia et al. 2016). Lycopene also inhibits abnormal growth of cells and is involved in tumor suppressor activity by decreasing the insulin-like growth factor induced cellular proliferation (effect on mitogens in various cancer cell lines) (Johary et al. 2012). The potential of lycopene derived functional drinks in the reduction of malignant transformation of oxidized cholesterol, especially in diabetic state, as well as delaying of carcinogen-induced phosphorylation of regulatory proteins and ceasing of cell division at the G0-G1 cell cycle phase has been reported (Elumalai et al. 2013; Naz et al. 2014). Various researchers reported the involvement of lycopene in the intrathymic differentiation regulation mechanism, which has a crucial role in inhibition of tumor growth in mammary gland by ensuring proper cell and organ functioning as it enables the cells to communicate with each other (Johary et al. 2012). Inadequate intake of dietary lycopene results in pathogenesis of insulin resistance and diabetes as suggested by various epidemiological studies (Elumalai et al. 2013). Thus, lycopene-rich fruits and vegetables such as watermelon are considered pivotal due to non-toxicity and without known side effects and its important role in prevention of chronic diseases.

17.3.2 β-Carotene

β-Carotene (secondary plant metabolite) is an unoxidized compound and one among the group of 600 compounds called carotenoids jointly. Being a polyene compound, it is derived from the acyclic structure, lipophilic in nature and exhibits low solubility in various solvents (water and ethanol) (Kong et al. 2018). β-Carotene ($C_{40}H_{56}$) is a long chain of 40 carbon atoms having 11 conjugated and 2 unconjugated, that is, total 13, double bonds in it (Kulczynski et al. 2017), obtained in *trans* configuration form and undergoes *cis* isomerization by heat and light reactions. β-Carotene is present in fruits and vegetables as orange and red colour pigment and the isomerization of double bonds promoted by high temperature results in colour brightening (Fratianni et al. 2010). β-Carotene serves as vitamin A precursor in body due to its structure identical to retinol, revealing the highest bioactivity (Shao et al. 2017). Only those carotenoids molecules exhibit provitamin activity that have β-ion ring (Eroglu and Harrison 2013), and there are two β-ionic rings present in the β-carotene molecule. Thus, two retinol molecules result by the cleavage at—C15=C15′– position of this chain.

Absorption of β-carotene in the intestine occurs directly by epithelial cells of intestine (Lin et al. 2018). Therefore, retinol conversion of β-carotene occurs in the small intestinal mucous membrane via passive diffusion. During conversion, carotenoproteins are formed via the retinal aldehyde form by the enzyme 15,15′-dioxygenase. However, the conversion is incomplete and only 1/6 of retinol activity is shown by this compound (vitamin A), that is, 1 mg of retinol is equivalent to 6 mg of β-carotene. Because of the lipophilic nature of carotenoids, β-carotene is dissolved in the lipid phase after getting released from food and has the tendency to accumulate in cell membranes and lipoproteins. β-Carotene converts partially to vitamin A because of its incomplete conversion. It (unconverted) is then secreted into the lymph and transported to the liver through chylomicrons as β-carotene, which remains unconverted and retinal esters are incorporated into chylomicrons. Many biological processes are affected by carotenoids: free radicals and singlet oxygen sweeping, vision process, photosynthesis and so on. The provitamin A supply in the human body is the most important function of β-carotene among its various other functions. Further, it is involved in the proper growth and development of embryo and proper sight, acts as the inhibitor of some genes exhibits antioxidant and anticancer effects (Bogacz-Radomska and Harasym 2016, 2018). The antioxidant and pro-oxidant properties of β-carotene make it a functional food ingredient (Maoto et al. 2019). β-Carotene is involved in protecting against LDL and HDL (high-density lipoproteins) by its neuroprotective effect because of its desirable power for ROS (reactive oxygen species) inactivation (Lin et al. 2018). The free radical scavenging by β-carotene occurs through electron transfer mechanism between β-carotene and free radicals, which results in carotenoid cation radical formation and hydrogen atom transfer, leading to a neutral carotenoid radical (Kulczynski et al. 2017).

The β-Carotene has various important health benefits, and some of them are: reconstruction of blood vessel walls due to increase in growth factor expression by intensifying the platelet aggregation (Kulczynski et al. 2017); support in cell growth and differentiation (involved in tissue and organ formation and maintenance such as heart and kidney) (Shao et al. 2017); maintenance of epithelial tissue integrity and growth; enhancement of immune system functioning; inhibition of tumor progression (in some cancers) (Shao et al. 2017; Nzamwita et al. 2017; Kulczynski et al. 2017); age defying properties by neutralizing the damaging molecules (Kim et al. 2014); prevention of scurvy (Pacier and Martirosyan 2015); and decrease of metabolic syndrome in the middle-aged adult (reduce type 2-diabetes risk) (Chen et al. 2017).

The most susceptible vitamin A deficiency group is reported to be the children and pregnant and lactating women. WHO reported that from about 2.5 lakh to 5 lakh children become blind among the 250 million vitamin A deficient preschool children (Nzamwita et al. 2017). The active precursor of vitamin A is β-carotene and it can play an important role in improving vision by helping the body in absorption of light in the eyes. The enzyme dioxygenase of small intestinal mucosa modulates gene function and converts β-carotene into retinol and thus acts as a factor for epithelial cell growth (Kulczynski et al. 2017).

Fruits and vegetables such as watermelon, carrots, mangos, sweet potatoes and spinach are the primary source of β-carotene as it cannot be synthesized by the animal body. Watermelon is a significant source of β-carotene, with 4.82 mg/g β-carotene in flesh of fresh watermelon (Kim et al. 2014). The health benefits associated with β-carotene as discussed increases its demand as the functional food ingredient. This in turn increases the importance of fruit and vegetables like watermelon, which are the rich source of β-carotene.

17.3.3 Vitamin C

Vitamin C comes under the category of water-soluble vitamins and is a potent antioxidant and essential nutrient. The human body is not able to synthesize it, and therefore should be incorporated via diet for survival (Padayatty et al. 2003). All the organic compounds exhibiting the biological activity of ascorbic acid are described as vitamin C ($C_6H_8O_6$) in general terms (Doll and Ricou 2013), having ascorbate and dehydroascorbic acid as its two main components (Pacier and Martirosyan 2015). It is a six-carbon lactone, synthesized by most mammalian species in the liver from glucose. But humans and some animals are not able to synthesize because of the absence of the enzyme gulonolactone oxidase in them, which is essentially required for the synthesis of the immediate precursor of ascorbic acid (2-keto-l-gulonolactone) (Nishikimi and Yagi 1996). Thus, a wide spectrum of clinical manifestations can occur due to the deficiency of vitamin C if not ingested by other dietary sources. Scurvy is a common example of vitamin C deficiency and can be proved to be lethal if not treated properly.

Vitamin C is well known for its physiological and biochemical actions, which are due to the electron donating nature and therefore makes it a reducing agent. Ascorbic acid from its six-carbon molecule donates two electrons from the position between 2nd and 3rd carbons double bond. In this way, it prevents the oxidation of other compounds and becomes an antioxidant and hence protects the body from the damaging effects of free radicals by neutralizing these free radicals (donate their own electrons). In this way, it ends the electron-stealing reaction of free radicals. However, the self-oxidation of vitamin C occurs (single-electron oxidation) in this reaction as the species formed after losing an electron becomes free radical (ascorbyl radical or semidehydroascorbic acid), but not actually so. The compounds formed are stable in either form (ascorbyl radical—half-life of 105 s and is relatively stable), fairly unreactive and act as scavengers. Thus, due to its chemical properties of reducing the free radicals (reactive) and forming less reactive compounds, vitamin C becomes a good free radical scavenging or quenching in nature (Padayatty et al. 2003). As explained, ascorbic acid is a strong antioxidant and can reduce reactive oxygen species (superoxide anion), hydroxyl radical, organic and nitrogen oxyradicals and other toxic radicals. In all aerobic cells, these reactions are of utmost importance, which in turn can help in prevention of cell and tissue damage. Vitamin C comes under the category of chain breaking antioxidant as it inhibits lipid peroxidation (Doll and Ricou 2013). The brain and adrenal cells are the main concentrate locations of vitamin C (Pacier and Martirosyan 2015). The two main ascorbate transportation systems involved in human body are sodium-dependent vitamin C transporters (SVCT—SVCT1 and SVCT2). SVCT1 transports most of the ascorbate in liver, intestine and kidney (epithelial cells) and the rest is transported in specialized cells (brain and eyes) (Pacier and Martirosyan 2015). As a result of some problems associated with consumption of synthetic supplements, the consumption of vitamin C from natural food sources such as fruits and vegetables has been recommended (Barba et al. 2015). Among various vitamin-rich fruits and vegetables such as grapefruit, cantaloupe, honeydew, kiwi, orange, mango, papaya, tangelo, strawberries, watermelon and tangerine (Padayatty et al. 2003), watermelon is also considered as an appreciable source of it (Padayatty et al. 2003; Jumde et al. 2015). The one cup watermelon fruit (portion size) contains 15 mg vitamin C (Padayatty et al. 2003) and 3.72 mg/100 g is present in fresh watermelon juice (Oberoi and Sogi 2015). About 20% of the daily vitamin C requirement can be fulfilled by a cup of watermelon juice. To prevent nutritive deficiency and scurvy, daily dose of at least 10 mg is required (Pacier and Martirosyan 2015) and for optimal benefits, at least 90–500 mg/day is recommended.

Some of the important contributions of vitamin C are: retard aging; protection of gums; protects from oxidation of vitamins and related effects; toxic metal removal from body; useful in glaucoma treatment by reduction in cataract formation; important in collagen fibres and various body hormones biosynthesis; anticancer properties (Ijah et al. 2015); cancer cell growth inhibition potential (either by inhibiting blood supply to growing cancer cells (Lemos et al. 2017) or by its pro-oxidant activity generation potential and thus suppresses cancer cell, depending on blood concentrations (Takahashi et al. 2012; Romdhane et al. 2017)); protects LDL and HDL oxidation; prevents cell damage (Kehili et al. 2017); suppresses oxidants (inhibits chronic disease development) (Choudhary et al. 2015; Pacier and Martirosyan 2015); treatment and prevention of common ailments (cold, scurvy, stress etc.) (Doll and Ricou 2013; Vaccaa et al. 2016); improves smoker's antioxidant status (oxidative stress reduction) (Hong et al. 2015); reduction in hypertension (Choudhary et al. 2015); and emotional/physical pressure management (reducing oxidative stress) (Pacier and Martirosyan 2015).

Deficiency of vitamin C in body due to less consumption of this phytochemical in diet could cause various serious problems, including decreased amounts of neurons resulting in impaired spatial memory in newborns as well as various degenerative diseases in adults (Pacier and Martirosyan 2015). The regular intake of diet enriched with vitamin C in proper amount is recommended for the maintenance and proper functioning of body and thus preventing present and future ailments (Naz et al. 2014; Choudhary et al. 2015). Regular intake of vitamin C rich natural sources can be proved to be beneficial for individuals within certain risk groups also (certain addictions, obese pregnant women, stressful environment etc.) (Sen et al. 2014).

Thus, keeping in view the health benefits of vitamin C, consumption of natural diet having fruits and vegetable like watermelon enriched with vitamin C is recommended in comparison to its synthetic supplements.

17.3.4 Citrulline

Citrulline (non-essential amino acid) is a potential antioxidant and vasodilator. It has an important role in the synthesis of nitric oxide in humans. Among natural resources, watermelon is considered as one of the citrulline-rich sources and citrulline was first isolated from this fruit. Variation in citrulline content was found among cultivars, varieties, flesh colours and tissues (Rimando and Perkins-Veazie 2005). The amount of citrulline content (DW) in watermelon is reported to be 7.9–28.5 mg/g, for seeded (16.6 mg/g) and seedless types (20.3 mg/g). The citrulline content of red flesh watermelons (7.9 mg/g) is reported to be slightly less than the orange (14.2 mg/g), whereas it is higher for yellow flesh (28.5 mg/g) watermelons (Table 17.2). On an average, on dry weight basis, rind (24.7 mg/g) of watermelon has more citrulline content than flesh (16.7 mg/g), but values reported were slightly low (1.30 mg/g (rind) and 1.90 mg/g (flesh)) on fresh weight basis (Rimando and Perkins-Veazie 2005). Thus, watermelon rind can be a good source of natural citrulline if used properly.

Citrulline, the final product of glutamine metabolism, is an effective arginine precursor and used in nitric oxide cycle in the liver and kidneys. Nitric oxide (NO) is a reactive component having an important role in the maintenance of health and artery vasodilation. Intestine transforms citrulline from ornithine (precursor of glutamine). Further, arginine (endogenous) and then nitric oxide from it can be synthesized by using citrulline, during the release of citrulline into circulation from the small intestine, which is then extracted by the kidney (Guoyao and Morris 1998). Endothelial nitric oxide synthase (eNOS) and its cofactors eventually convert arginine to nitric oxide (Kondo et al. 2009) (Fig. 17.3). In addition to important well-known functions of nitric oxide as arteries vasodilator and health promoter, its other roles are: involvement in fat and energy metabolism, composition and regulation of insulin sensitivity (Azizi et al. 2020).

Nitric oxide synthesis is not only diminished but its bioavailability is also decreased if the number of reactive oxygen species (ROS) increases, particularly superoxide (O_2^-) by generating peroxynitrite ($ONOO^-$). The oxidative stress status, related chronic inflammatory disorder development and progression aggravate by the togetherness of ROS & $ONOO^-$. Citrulline helps in combating this by increasing arginine levels in the plasma, which further convert in nitric oxide as explained previously (Schwedhelm et al. 2008). Citrulline also inhibits enzyme arginase,

Table 17.2 Citrulin (mg/g) in different flesh colour watermelon (flesh and rind with) (values are means of seeded and seedless varieties)

Fruit colour	Flesh (DW)	Rind (DW)	Flesh (FW)	Rind (FW)
Red	7.90	15.60	1.00	0.80
Yellow	28.50	29.40	3.50	1.50
Orange	14.20	28.20	1.80	1.50

Source: Rimando and Perkins-Veazie (2005)

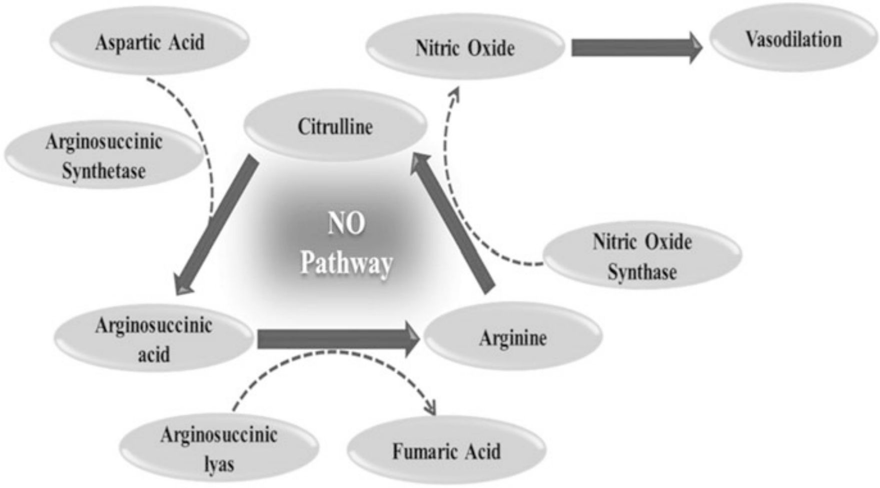

Fig. 17.3 Nitric oxide metabolic pathway. (Source: Azizi et al. 2020)

which is upregulated in diabetes and cardiovascular disease and involved in the conversion of arginine into ornithine and urea. The potential antioxidant properties of citrulline are also exhibited by some other mechanism through which glycaemia is affected by this amino acid. Citrulline and watermelon extract beneficially affect the inflammation and glycaemic status of body in case of diabetes mellitus (Azizi et al. 2020). As already explained, the health beneficial potential (vasodilation effect) of citrulline (arginine precursor) is assumed to be mainly due its role in increasing arginine availability for the synthesis of nitric oxide. Nitric oxide is a gas (endothelium secretion), which is involved in starting a signalling cascade and soluble guanylate cyclase (sGC) enzyme activation, which in turn enhance the production of guanosine monophosphate cyclic (cGMP). This enhancement promotes vasodilation by the relaxation of conducting and resistance arteries smooth muscles (Archer et al. 1994).

The skeletal muscle metabolism has been proposed to be affected by lower nitric oxide bioavailability (both directly and indirectly), which might develop insulin resistance further (Timmerman et al. 2010). During obesity and diabetic conditions, disrupted nitric oxide balance and reduced bioavailability are reported in different studies (Higashi et al. 2001). The diabetic's complications and signalling of insulin in insulin-sensitive tissues are reported to be affected by oxidative stress and inflammation. Thus, augmented oxidative stress and inflammation resulted in declined sensitivity to insulin, intensified resistance to insulin and undermined function of mitochondria (Azizi et al. 2020). The insulin sensitivity might be improved by citrulline as it is involved in the insulin receptor substrate1 (IRS1) activation and serine 1101 phosphorylation inhibition. The tyrosine phosphorylation in insulin receptor substrate leading to phosphoinositide 3-kinase (PI3K) activation occurs after binding of insulin to its receptors, followed by Akt (protein kinase B) phosphorylation. This is the main factor of insulin transduction pathway and glucose metabolism regulation (Hall and Granner 1999). Citrulline enhances the Akt phosphorylation as induced by insulin and at the upstream of Akt, the tyrosine phosphorylation in IRS1 is increased by citrulline. The ability of citrulline to be recycled into arginine (anti-inflammatory) gives it the potential to affect inflammation (Breuillard et al. 2012). Additionally, citrulline can reduce the cytokine (pro-inflammatory). Otherwise, it contributes to insulin resistance and restricts IRS-1 phosphorylation on tyrosine residue and in turn increases type 2 diabetes and obesity risk (Azizi et al. 2020). Potential of citrulline in reduction of inflammatory cytokines and enhancement of anti-inflammatory cytokines has been reported in the literature (Romero et al. 2006).

As explained earlier, the antioxidant potential of citrulline may be due to its nitric oxide synthesis attribute. The increase in production of nitric oxide resulted in the reduction of oxidation sensitive genes expression. Additionally, the recycling pathway for conversion of citrulline to nitric oxide through arginine (synthesized from citrulline in endothelial and other cells) may be the chief source of available arginine. Asymmetric dimethylarginine (ADMA), which is the competitive eNOS (endothelial nitric oxide synthase) inhibitor, has to compete with this extra arginine (Azizi et al. 2020). The production of hydroxyl radical occurs through the exit of hydrogen peroxide and superoxide through Haber–Weiss chemistry. The level of hydroxyl radical can be decreased by citrulline (potential antioxidant) directly and indirectly.

This can be due to chelating hydroxyl radical production substrate (copper(II)). Moreover, direct interaction of citrulline through its α-amino group in protonated NH_3 state with hydroxyl radicals resulted in a non-toxic product, most probably water (Azizi et al. 2020).

In addition to the health benefits explained above, citrulline is: a strong free radical scavenger and osmolyte in drought/salt stress conditions (Soteriou et al. 2014); helpful in anaemia prevention, relaxation and performance of muscle (Choudhary et al. 2015); enhances functioning of endothelial cells in coronary artery disease patients (L-arginine) (Hong et al. 2015); and improves cardiac sympathovagal balance (supplementation with L-citrulline for 8 weeks) in obese postmenopausal women (Wong et al. 2016). The bioavailability of citrulline is reported to more from natural source form than that of synthetic form (Barba et al. 2015).

Various studies reported that watermelon extract and citrulline could have the potential to improve the synthesis of nitric oxide. Thus, it can possibly be helpful in reducing the oxidative stress and inflammation, thereby decreasing the risk of various diseases, and improving the glycaemic status in diabetes mellitus as well (Azizi et al. 2020). In comparison to those having without dietary watermelon in their meal, consuming watermelon juice (three meals) in high level regularly is reported to have increased the arginine and ornithine levels in plasma (Said 2014). Thus, the intake of watermelon juice can be helpful in increasing the level of arginine in plasma and prove to be beneficial in various body functions (Said 2014).

17.3.5 Total Polyphenolic Content

Phenolic or polyphenols/polyphenolic compounds are plant constituents having phenols as large multiple structural units. These are the structural class organic chemicals (includes phenolic acids, stilbenes, flavonoids and lignans) having potential antioxidant capacity (Abourashed 2013). Among plant phenolics, flavonoids and phenolic acids are the most pervasive and have scavenging (free radical), quenching (singlet oxygen formation) and reducing properties. Currently, dietary phenolics are of considerable interest and the reason is their possible potential as both antioxidant and anticarcinogen. These compounds are the paramount group of bioactive compounds and secondary metabolites of plants produced during photosynthesis (by absorption of sunlight and high level of oxygen). Polyphenols undergo extensive enzymatic modifications after intake (oral) and absorption, and at intestinal and liver, it levels leads the synthesis of various compounds (methylated and sulfated compounds, glucuronidated) (Vaccaa et al. 2016). Like phenolic acids, flavonoids also have polyphenolic structure and are also the secondary plant metabolites. The polypropanoid pathway with phenylalanine as the start-up molecule is used for their synthesis. All flavonoids have basic 15-carbon atom structure (C6-C3-C6) having two aromatic rings (A and B) and a heterocyclic ring (C) containing one oxygen atom. Among the 6000 total identified and isolated flavonoids, only eight are distributed widely from the several hundred plant isolated flavonoids (quercetin, catechin, rutin, anthocyanidins, epicatechin, myricetin, kaempferol, and luteolin) (Seigler 1998; Austin and Noel 2003).

According to the literature, the amount of polyphenols (total phenolic and flavonoids) present in watermelon varies between cultivars, types and even in different sampling areas. Average of the total phenolic content and flavonoids of samples from different areas (Blossomend, Stemend, Heart, Peripheral) ranged from 102.2 to 122.3 mg GAE/kg and 131.7 to 157.0 mg RE/kg, respectively (FW) (Tlili et al. 2011). The total phenol and flavonoid content within different cultivars also varies and ranged between 89.0 and 147.3 mg GAE/kg and 111.30 and 176.10 mg RE/kg, respectively (FW) (Tlili et al. 2011). Total phenols of amount 116 mg GAE/kg has been reported in the watermelon samples of national markets of France (Brat et al. 2006). However, some significantly higher values have been also reported, that is, 870–910 mg GAE/kg (FW) for red flesh colour watermelons (Perkins-Veazie et al. 2002). These variations in the amount of polyphenols reported in the literature may be due to difference in cultivar, geographical area, sampling area, type and so on. Among the eight high phenolic fruits that provide 50–80% (of Spanish and American diet) of daily phenol, watermelon stands at number four (Vinson et al. 2001). It has been reported that flavonoid content of some watermelon is higher than tomatoes (Stewart et al. 2000), and approximately same to high pigment (cherry) (Lenucci et al. 2006).

The antioxidant attribute of polyphenols is specifically due to the mechanisms of their free radical scavenging potential (reactive oxygen or nitrogen species), free radical producing enzyme inhibition, chelating metal suppression and antioxidant defense (upregulation or protecting). In the molecular structure of phenolic and flavonoid, mainly the free hydroxyl groups and their number are responsible for their reduction activity and steric hindrance strengthens them further (Rice-Evans et al. 1996; Ghasemzadeh and Ghasemzadeh 2011). Thus, polyphenols have the benefits of preventing and repairing the damage in body caused by free radicals and reactive oxygen species mainly during the conditions, such as obesity and diabetes. This is due to their antioxidants effects as well as multiple signalling pathways modulation in beta cells (β-cells) of pancreatic islets, hepatocytes, adipocytes and myofibrils of skeletal muscles (Garcia-Perez et al. 2017). Anticancer and anti-inflammatory attributes of polyphenols have also been reported (in vivo and in vitro studies) (Choudhary et al. 2015). Last, but not the least, various other protective effects of polyphenols have also been reported, namely, protection against inflammation, neurodegenerative disorders, diabetes, osteoporosis, high arterial pressure, headaches and arthritis (Maoto et al. 2019; Vaccaa et al. 2016).

However, it is clearly understood that respective intakes and bioavailability of phenolic compounds in body affect their associated health benefits. Among food manufacturers, nutritionists and consumers, polyphenols have gained considerable interest because of their less side effects with high potential towards medicinal and therapeutic health effects (Barba et al. 2015; Castro-Lopez et al. 2017). Various studies have been done till date that report the potential health beneficial component present in watermelon. But a lot of research is still ongoing for the identification and characterizations of polyphenols contained by watermelon and are yet to be discovered. Various studies have proved that natural sources of photochemical are much better than their synthetic counterparts in most of cases. Thus, consumption of watermelon juice and its other parts can serve as a medicinal alternative because of the presence of various health beneficial constituents as reported in the literature (Maoto et al. 2019).

17.4 Health Benefits

Watermelon, not only its flesh but other parts like rind, peel and seeds are also a good source of various phytochemical, having health beneficial potential. Health benefits of phytochemical present in watermelon and their possible disease prevention potentials as reported in the literature are given in Table 17.3. In the characterization and antioxidant properties section, most of the beneficial effects associated with individual phytochemicals present in watermelon are discussed already, and so some common but important health benefits are discussed in this section.

17.4.1 Lower Blood Pressure and Improve Heart Health

High blood pressure leads to chronic disease and premature death. Watermelon consumption supports the nitric oxide production in body because of citrulline (arginine precursor—later on converted into nitric oxide), which is present in good amounts in it. Nitric oxide relaxes and dilates blood vessels by relaxing the inner

Table 17.3 Health benefits (reported effect and disease prevention) of phytochemicals present in watermelon

Phytochemical	Benefits		References
	Possible effects/results	Disease prevention	
Lycopene	Serum lycopene associated with decreased risk; prevents inflammation by reducing production of pro-inflammatory mediators; inhibit abnormal cell growth and proliferation	Breast, cervical, bladder and prostate cancers	Maoto, Beswa and Jideani (2019) and Azizi et al. (2020)
Lycopene	Reduce oxidative stress and its damaging effects that can cause osteoporosis	Osteoporosis	Choudhary et al. (2015)
Lycopene	Improved plasma agitation	Hypertension	Choudhary et al. (2015)
Lycopene	Lowered cholesterol synthesis	High cholesterol	Vaccaa et al. (2016)
β-carotene	Reduced the hazard ratio in cardiovascular disease and coronary heart diseases	Cardiovascular mortality/heart attack	Choudhary et al. (2015)
β-carotene	Precursor of vitamin A	Eye health	Maoto et al. (2019)
Vitamin A	Enhances optimal eye functioning	Eye health	Maoto et al. (2019)
Citrulline	Improve erectile functions	Low libido	Maoto et al. (2019)
Citrulline	Improved obese postmenopausal women's cardiac sympathyovagal balance, increased plasma arginine	Obese postmenopausal women	Wong et al. (2016) and Said (2014)
Citrulline	Can reduce oxidative stress, inflammation and insulin resistance and improve type 2 Diabetic condition; vasodilator	Type 2 diabetes; blood pressure	Azizi et al. (2020)
Vitamin C	Prevents and treats a variety of ailments, scurvy and a simple cold	Flue and scurvy	Choudhary et al. (2015) and Doll and Ricou (2013)
Vitamin C	Stroke reduction	Stroke	Pacier and Martirosyan (2015)
Vitamin C	Decrease 58.2% serum alanine aminotransferase and 49.4% of high sensitivity C-reactive protein and also minimize damage and slow down disease progression	Liver disease	Pacier and Martirosyan (2015)
Vitamin C	Least risk of inadequacy or adverse health effects	Human metabolism	Pacier and Martirosyan (2015)
Polyphenols	Preventing and repairing the damage in body caused by free radicals and ROS	Obesity and diabetes	Garcia-Perez et al. (2013)

muscles of vessels and helps in reducing blood pressure. Watermelon or its juice supplementation in diet may reduce arterial stiffness and blood pressure of people suffering with high blood pressure. Citrulline has also been found to reduce arterial stiffness in postmenopausal women (Figueroa et al. 2013). Watermelon contains appreciable amounts of potassium, which lowers high blood pressure and acts as electrolyte during physical exercise (regulates blood pressure). Regular consumption of watermelon leads to fewer fatty deposits inside the blood vessels and has beneficial effects on atherosclerosis (Poduri et al. 2013).

17.4.2 Reduced Insulin Resistance

To control the blood sugar, insulin is a vital hormone and body resistance to insulin can lead to metabolic syndrome and type-2 diabetes due to elevated blood sugar levels. Watermelon intake reduces insulin resistance due the amino acid arginine present in it as reported in some studies (Azizi et al. 2020).

17.4.3 Reduced Muscle Soreness and Energy Booster

According to the data reported by some studies, watermelon juice due to citrulline and arginine is effective in decreasing post-exercise muscle soreness and improves athletic performance (Sureda and Pons 2012). Watermelon boosts energy level due to potassium (electrolyte) and vitamin B (responsible for energy production) present in it. Data documented in the literature on watermelon juice (or citrulline) and exercise performance gives mixed results.

17.4.4 Reduce Inflammation and Oxidative Stress

Lycopene, citrulline and carotenoids present in watermelon help in reducing inflammation and oxidative stress by scavenging free radicals and improving nitric oxide production (Perkins-Veazie et al. 2007; Wang 2012).

17.4.5 Improves Body Hydration, Digestion and Health

High amount of water (>90%) makes watermelon one of the best sources of hydration and is found better than alcohol or caffeine in terms of being a diuretic. Watermelon can aid digestion due to a high amount of water and fiber. It is a natural thirst quenching drink and increases urination without stressing the kidneys. The presence of vitamin C in watermelon juice may help in keeping the gums healthy. Different phytochemical and antioxidants help in keeping the skin and hairs healthy, reduce cell damage and strengthen immunity if watermelon is consumed regularly in diet (Romdhane et al. 2017; Maoto et al. 2019).

17.4.6 Anticarcinogenic Benefit

Lycopene is a strong antioxidant and has anticarcinogenic properties and watermelon is a good source of it, hence reducing the extent of cancer insurgence and preventing the onset of various types of cancers. Watermelon with two cup serving having 20 mg of lycopene has the power to fight free radicals in body and in turn protects against different types of cancers. It is reported that in prostate cancer cells, lycopene exhibits chemopreventive properties and has also been helpful in treatment of HPV (human papillomavirus) infection (HPV leads to uterine cancer) (Singh and Goyal 2008; Maoto et al. 2019).

17.4.7 Watermelon Preservation

The preservation of watermelon is important, to preserve its valuable quality attributes, but because of its perishable nature as well. Watermelon has pH (5.2–6.7) and water activity ranging between 0.97 and 0.99 (Lemos et al. 2017). The high value of water activity and low acidity make it susceptible to pathogenic microorganism, mainly to Gram-positive bacteria (sensitive to low acidity). Watermelon should be processed into various products to fulfil consumer's need and to extend the shelf life as well as increase its utilization. However, some high heat treatments, such as drying, pasteurization and sterilization, resulted in loss of some nutrients and phytochemicals. Some novel processing methods, such as high-intensity pulsed electric, thermosonication and high pressure processing, resulted in retention of valuable nutrients in watermelon with extended shelf life as reported by various studies (Choudhary et al. 2015; Barba et al. 2015; Maoto et al. 2019).

17.5 Conclusion

The excellent refreshing taste and presence of phytochemicals having various health benefits might be the reason for increasing attention towards watermelon and its value-added products. The antioxidants present in watermelon are mainly lycopene, β-carotene, phenolics, vitamin C and citrulline and they have stimulated great attention recently, and the reason is their antioxidant potential and protection against various diseases. These phytochemicals have been reported for various therapeutic and pharmacological activities, such as hepatoprotective, analgesic, anti-inflammatory, laxative, gastroprotective and anticarcinogenic which are directly or indirectly related to their antioxidant potential. Additionally, lower amounts of calories, sodium content and cholesterol make it an excellent food for weight loss alternative. Because of these quality attributes, regular watermelon consumption might be helpful in the enhancement of self-healing system of body and in turn important in disease prevention and proper functioning of body.

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Kachnar (*Bauhinia variegata*) 18

Shiv Kumar, Poonam Baniwal, Jaspreet Kaur, and Harish Kumar

Abstract

Bauhinia variegata is deciduous tree, native to tropical and temperate regions. It is small to medium sized tree, brownish gray in color. The parts of *B. variegata*, that is, flowers, stem, bark, root, and seeds are well known for their medicinal and therapeutic values. Many researches claim that the plant exhibits antitumorous heapatoprotective, anti-inflammatory, antioxidant, antibacterial, hypolipidemic, wound healing, antiulcer, nephroprotective, antidiabetic, astringent, anticataract, cytotoxic activities. In Ayurveda, the plant parts are used in various medical formulations. Stem bark is used in treating disorders such as Galaganda, Gandamala, Arbuda, Kapha-Pitta, and Ashthila. Flowers are used for the treatment of Pitthaghna, Rakta pradaraghna, Kaasghna, and Kshyaghna. Buds, roots, and bark have good antioxidant properties. The plants contribute a variety of tannins, phenolic compounds, phytosterols, flavonoids, lysine, oleic acid, glycosides, linoleic acid, saponins, etc. Besides this, the plant and its parts are used for many conventional activities, such as mosquito control, fiber making, dying industry, and agricultural operations. The current chapter is designed to reveal the biological, medicinal, chemical, and nutritional importance of multipurpose *B. variegata* plant.

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Keywords

Bauhinia variegata · Antioxidant properties · Phenolic compounds · Antidiabetic · Health benefits

18.1 Introduction

Botanical Name: *Bauhinia variegata.*

Common names: Kaanchana, Swet-kanchan, Orchid tree, Bauhinia, Camel's foot, Kachnar, Mountain ebony, Gurial, Kachnal, Koiralo.

B. variegata (Kachnar) is deciduous, fast growing flowering tree, mainly distributed in the tropical countries as well as carnatic and deccan regions of southern India and stony hills of Circars (Sahu and Gupta 2012). The word Kachnar means "A beautiful glowing lady" in Sanskrit (Irchhaiya et al. 2014). It has been used in the folk medicine for variety of purposes. For instance, it is used for the treatment of different kinds of infections, pathologies, mainly diabetes, in addition to inflammation and pain owing to the existence of various phytochemicals residing in the plant. The commonly isolated chemical constituents from the plant are kaempferol-3-glucoside, β-sitosterol tannins, carbohydrates, amides, vitamin C, reducing sugars, crude fibers, protein, phosphorus, calcium, quercetin, quercitrin, rutin, apigenin-7-*O*-glucoside, apigenin, dotetracontan-15-en-9-ol, 13-diol, and heptatriacontan-12 (Naeem and Ugur 2019). Polyphenols due to their firm antioxidant activity protect cell components in opposition to oxidative damage and prevent the harmful effects on lipids, proteins, and nucleic acids in cells. High level of phenolic compounds exhibits high antioxidant aptitude in plants. The antioxidant prospective of medicinal or therapeutic plants is largely because of the phenolic compounds redox effects which creates the phenolic components to function as singlet oxygen, hydrogen donors, and reducing agents (Hakkim et al. 2007). The hydroxyl groups of phenolic compounds considered as a significant plant constituent because of their considerable scavenging ability. The most considered and largest polyphenols, that is, flavonoids, are receiving attention as antioxidants owing to their high competence of free radical scavenging activity (FRSA) (Souza et al. 2008). The compounds synthesized by plants, that is, antioxidant, like the derived products, are generally phenolic metabolites range from uncomplicated to vastly polymerized complexes. Many research studies have revealed that the utilization of foods rich in phenolic compounds helps preventing the diverse chronic diseases (Hollman 2001). Various experimental in vitro and in vivo models have been conducted to study the biological properties of several *Bauhinia* species and it is reported that the medicinal properties are because of flavonoids present in them (Rao et al. 2008). Also the results indicated that the free radical scavenging due to antioxidants has a huge value in deadly disease treatment and prevention. It has been also observed that the stem bark of *B. variegata* contains total phenolic compounds in large amount, therefore pointing out this plant can be employed as a significant source for the groundwork of not only nutraceuticals as potent antioxidants as well as for cure of other foremost health complications (Gautam 2012). Overall, *B. variegata* perhaps contemplated as a model herbal drug for investigational studies including various free radical induced disorders like cancer, diabetes, and atherosclerosis (Pandey et al. 2012).

18.1.1 History

B. variegata is native to the tropical and temperate Indian subcontinent (e.g., Nepal, India, Pakistan, and Bhutan), Southeastern Asia (e.g., Vietnam, Myanmar, Thailand, and Laos), and China. This plant is well described in ancient Indian science of life known as Ayurveda and its Stem bark and flowers are used as medicine in various formulations. The bark of Kachnar is used in disorders like galaganda (Goiter), gandamala (Lymphadenopathy) (Manoj et al. 2013), ashthila [Benign prostatic hyperplasia (BPH)], kapha-pitta dosha disorders, and arbuda (Tumor). Whereas the flowers have rakta pradaraghna (cures dysfunctional uterine bleeding), pittaghna (pacify pitta dosha), kshyaghna (antitubercular), and kaasghna (curing cough) properties. However, it is also practiced in treatment of various carcinomas (Patil et al. 2010). Kachnar (*B. variegata*) is also an eminent tree species to the people of Himachal Pradesh.

18.1.2 Production (India and World)

B. variegata was introduced and can be found cultivated and naturalized in Africa, West Indies, tropical America, and Pacific and Indian Ocean islands (Flora of China Editorial Committee 2014; ILDIS 2014; USDA-ARS 2014).

18.1.3 Botanical Description

B. variegata is a small to medium sized tree amid a small bole along with a widen crown. The tree attained up to 15 m height of and about 50 cm diameter. The size of tree is much smaller on comparison in dry forests. The bark is soft to somewhat fissured and scaly, light brown gray in color. The inner part of bark is bitter, fibrous, and pinkish colored. The twigs are light green, zigzag when young, slender, angled, and to some extent hairy, flattering brownish gray. The leaves of tree are having tiny stipules of about 1–2 mm and early caduceus. The petiole is puberulous toward glabrous, that is, 3–4 cm whereas lamina is generally ovate to spherical and a lot broader than elongated, that is, 6–16 cm in diameter. The tips of lobes are rounded broadly. Usually the upper surface is glabrous and lower is glaucous although becomes glabrous once completely mature. The flower (Fig. 18.1) bunches are racemes and unbranched at the twig ends. Fewer flowers have hypanthium, which is green, narrow basal tube, short, a stalk like, and stout stalks. A pointed five angled forms a bud which is light green and a calyx covered with hair that splits open on one

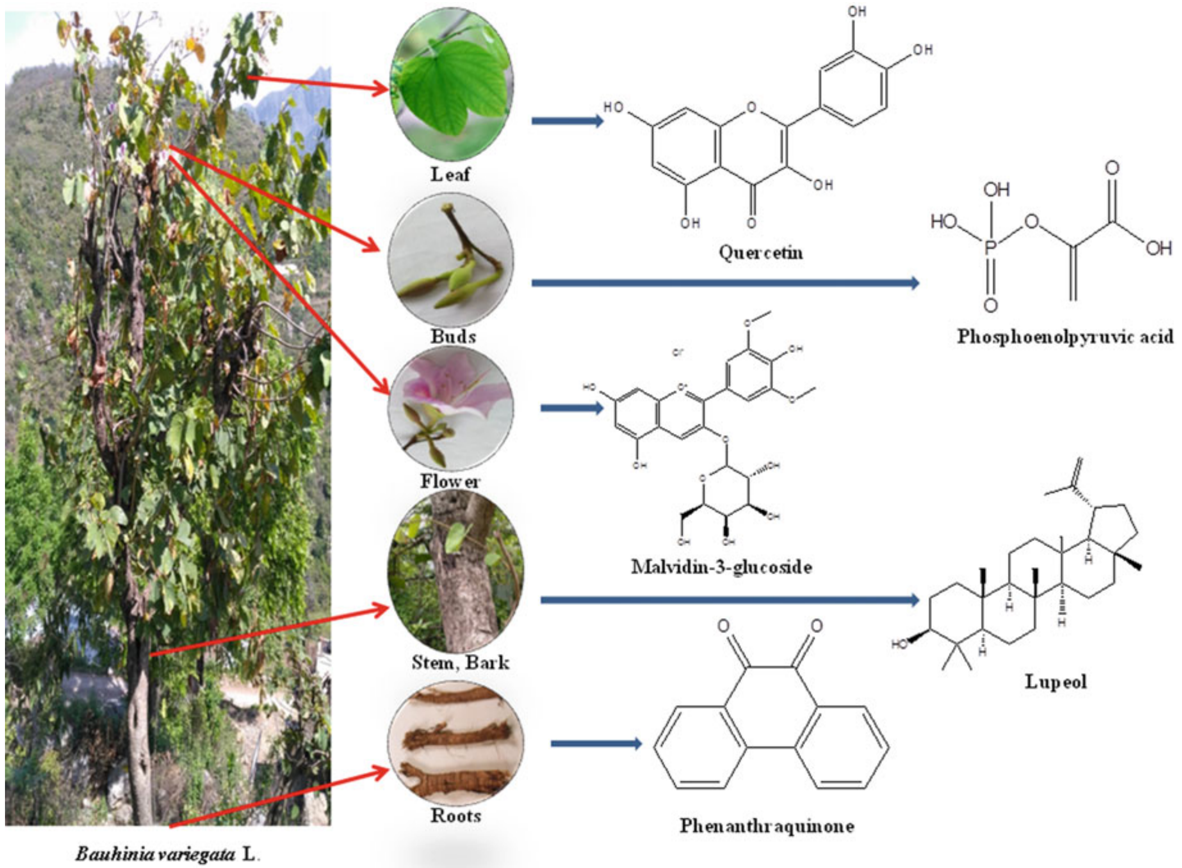

Fig. 18.1 *B. variegata* plant and its parts with their chemical constituents

side while the other sides remain attached. The flower has five petals which are somewhat unequal, lessened to base, and curvy margined. Also, the flower contains five stamens (curved), extremely slender, stigma (style and dot like), and pistil is curved with single celled ovary (green, narrow) (Patil et al. 2012). Pods are band-shaped, dehiscent, diagonally striate; hard, long, flat and each contains about 10–15 seeds. The seeds are flat, brown in color, and almost circular through coriaceous testa (Dey and Das 1988; Prakash et al. 1978).

18.1.4 Biology

In India, it is a deciduous tree and remains leafless from January to April month. Leaf fall occurs in the month of November and December. The process of flowering occurs when the plant is leafless. The flowering process starts at an age of about 2–3 years. The germination starts, when the seeds disperse from pods, on the places having favorable moisture and light situations. During unfavorable conditions the radicle get dried or demolished by birds.

18.2 Antioxidant Activity

Quercetin and flavonoids are the strong antioxidants and acknowledged to modulate the actions of various enzymes owing to their interaction with biomolecules (Maldonado et al. 2003). Aqueous and ethanolic extracts of *B. variegata* root produced an important antioxidant activity and it is accomplished by in vitro free radicals scavenging using 1,2-diphenyl-1-2 picrylhydrazyl (DPPH), nitric oxide, and superoxide (Rajani and Ashok 2009). It may be the flavonoids and more phytochemicals present in extracts of the plant. The ethanolic extract produced significantly much better antioxidant activity as compared to other extracts (Sharma et al. 2011a). Leaf, bark, and flowers have FRSA. More the amount of total phenolic content present in extracts more is the antioxidant activity exhibited. Sharma et al. (1968) studied that both the ethanolic and aqueous extracts of root possesses important antioxidant activity by scavenging of a variety of free radicals, for instance 1,2-di phenyl 1-2 picrylhydrazyl (DPPH), superoxide, nitric oxide. It was observed that various extracts of the plant produce significant DPPH (1,2-diphenyl 1-2 picrylhydrazyl). Pandey and Agarwal (2009) observed antioxidant activity by inhibiting of Thiobarbituric Acid Reactive Substances (TBARS) and reported a significant FRSA, antioxidant activity, and hydroxyl radical scavenging in vitro in the *B. variegata* methanolic extract. They confirmed the existence of phenolic compound flavonoids, tannin, etc.

Antioxidant activity was also evaluated in the crude extracts and fractions of *B. variegata*. DPPH radical scavenging assay was used for performing the antioxidant activity. The study revealed that the fraction of *n*-hexane, methanol, and ethyl acetate shows modest scavenging activity contrast to the standard quercetin. Incidence of phytoconstituents such as β-sitosterol, oleic acid is found in reducing the hyperlipidemic conditions and these components have been earlier reported in *B. variegata* (Bopanna et al. 1997). In other research extract of methanol from tree bark with its parts was assessed for DNA protective activity and antioxidant. The results showed that it has an important antioxidant activity and would be able to stop H_2O_2-induced oxidative damage to pBR322 DNA. Phenolic or flavonoid compounds present in the bark of *B. variegata* may attribute strong anti DNA protection ability and oxidative activity. Furthermore, a major correlation among the antioxidant activity and total phenolic or flavonoid content was also studied by Sharma et al. (2011b). Chemical investigation of methanolic extract from the *B. variegata* stem directed the way to segregation of bioactive phytoconstituents, namely quercetin, lupeol, kaempferol, and β-sitosterol (Jash et al. 2014). These phytochemicals isolated from the extracts are well ascertained and known to show important biological movements.

18.3 Chemical Constituents of the Plant (Fig. 18.1) and the Pathways Involved (Table 18.1)

- An aerial part contains ombuin, kaempferol, kaempferol 7,4-dimethyl ether-3-*O*-β-D-2 glucopyranoside, triterpene, kaempferol-3-*O*-β-D-glucopyranoside, hesperidin, and isorhamenetin-3-*O*-β-D-glucopyranoside (Gupta et al. 1980).
- Stem bark of *B. variegata* contains quercitroside, kaempferol-3-glucoside, lupeol, and β-sitosterol isoquercitroside, rutosidemyricetol glycoside, and kaempferol glycosides (Yadava and Reddy 2003; Gupta et al. 1980). Whereas stem extract contains 2, 7-dimethoxy-3-methyl-9,10 dihydrophenanthrene-1-4, phenanthraquinone, dione (Bauhinione) (Zhao et al. 2005).
- Leaves contain lupeol, alkaloids, oil, fat, glycoside, phenolics, lignin, saponins, terpenoids, β-sitisterol, tannins, kaempferol-3-glucoside, quercitin, rutin, apigenin, apigenin-7-*O*-glucoside amides, reducing sugar, carbohydrates, protein, fiber, vitamin C, calcium, and phosphorus (Shariff 2001).
- Seeds contain protein, fatty oil containing linoleic acid, oleic acid, palmitic acid, and stearic acid. Reddy et al. (2003) noted a new flavone in root extract of *B. variegata* is 5,7-dimethoxy-3′-4′-methyleneflavone.
- Flowers contain many components, such as reducing sugars, flavonoids, terpenoids, saponins, tannins, cardiac glycosides, and steroids (Uddin et al. 2012).

Table 18.1 Activity reported by various researchers and model used

Sr. no.	Reported activity	Author	Parts used	Model used
1.	Anti-inflammatory	Rao et al. (2008)	Nonwoody aerial parts	Carrageenan induced hind paw edema
2.	Antidiabetic	Azevedo et al. (2006)	Leaves	Glucose induced diabetes
3.	Chemoprevention and cytotoxic effects	Rajkapoor et al. (2006)	Stem	*N*-nitrosodiethylamine induced investigational liver and tumor study in rats
5.	Antitumorous	Rajkapoor et al. (2003a)	Stem	Produce Dalton's ascetic lymphoma
6.	Anticarcinogenic	Pandey and Agarwal (2009)	Stem, bark	DMBA and croton oil induced skin carcinogenesis in mice
7.	Antibacterial	Parekh et al. (2006)	Stem, bark	Against bacterial strains
8.	Antiulcer	Rajkapoor et al. (2003b)	Stem	Gastric ulcer tempted by pyloric ligation and ulcer modal induced by aspirin
9.	Hepatoprotective	Bodakhe and Ram (2007)	Stem, bark	CCl4 induced hepatotoxicity
10.	Hemagglutinating	Wassel et al. (1989)	Crude seed	Hemagglutinating actions through proteins
11.	Antimicrobial	Pokhrel et al. (2002)	Stem, bark	Against bacterial strain
12.	Hematinic	Dhonde et al. (2007)	Stem, bark	Phenylhydrazine administration
13.	Anticataract	Bodakhe et al. (2012)	Stem, bark	Chick embryo and ovine lens model
14.	Nephroprotectivity	Sharma et al. (2011a)	Root	Nephrotoxicity model induced with gentamicin
15.	Wound healing	Sharma (2010)	Root	Incision and excision wound models

18.4 Health Benefits of *B. variegata*

B. variegata is extensively used as a therapeutic/medicinal plant in the tribal, Unani, Homeopathy, and Ayurveda, medicinal systems in India. It is believed to possess antimicrobial, antitumor, anti-inflammatory, hepatoprotective, hemagglutination, and antigoitrogenic properties (Mali et al. 2007).

18.4.1 Bark

The bark is used as alliterative, antitumour, antidiabetic, anthelmintic, alternative astringent, washing ulcers, obesity, and tonic (Rajkapoor et al. 2006; Prashar et al. 2010). It is used for the treatment of ulcers, scrofula, and various diseases of skin. Extract of bark is used in control of diarrhea. The extracts of *B. variegata* show a FRSA comparable to that of vitamin C. The phenolic, flavonoids, and other phytochemical elements present in it exhibit antioxidant activity and help in averting or showing oxidative stress allied degenerative ailments (Bhatia et al. 2011). The study regarding anticataract activity was carried out on chick embryo and ovine lens model with the use of flavonoid named rhamnocitrin which is isolated from the bark of tree. The study showed that rhamnocitrin helps in preventing the lens against cloudiness (Bodakhe et al. 2012). The significant reduction in feed intake and weight of high caloric diet fed female rats were observed when handled with methanolic extract of stem, barks, and root of tree. The study revealed that in the stems α-sitosterol is present and also, the extract has the tendency to elicit the brain serotonin level and reduce the lipid profile (Rajkapoor et al. 2009). Extract from bark of stem of *B. variegata* reveals significant hepatoprotective activity (Bodakhe and Ram 2007). Extract made from bark of stem has antimicrobial activity aligned with *Shigella dysenteriae*, *Salmonella typhi, Bacillus subtilis, Vibrio cholera, Pseudomonas aeruginosa*, and *Staphylococcus aureus* (Pokhrel et al. 2002). Rajkapoor et al. (2009) isolated flavanone and for cytotoxic activity was tested aligned with 57 human tumor lines. The results concluded that the cytotoxic activity was shown due to flavanone against human tumorous cell. The extract of ethanol of the stem bark is an immunomodulatory agent (Ghaisas et al. 2009). Ethanol extract from bark of *B. variegata* contains protein resembling to insulin, therefore exhibits significant antidiabetic activities (Azevedo et al. 2006; Koti et al. 2009). The chloroform and watery concentrate of bark has anthelmintic properties (Bairagi et al. 2012). The aqueous extracts from the root of *B. variegata* produces significant dose-dependent analgesic activity (Rajani and Ashok 2009). Patil et al. (2010) revealed that water/acetone extract and the compounds isolated from stem bark of *B. variegata* showed primarily significant action on in vitro neutrophils of human in all parameters, which are comparable to standard and control at different concentration signifying the potential immunostimulating effect.

18.4.2 Leaves

The juice extorted from leaves and roots of *B. variegata* is used by people of tribe named Gond of the Indian state named Madhya Pradesh to treat chest pain. The leaves of the tree have molluscicidal activity which is due to the quercetin and saponin present in them (Singh et al. 2012). The study conducted by Prashar et al. (2010) on high fat fed rats showed that the orally administered ethanolic concentrate was found to be successful in suppressing hyperlipidemia occurred due to high fat diet and suggests its valuable utilization as an antiatherogenic drug. Similar results were found by Kumar et al. (2011) while studying the antihyperlipidemic activity tyloxapol (Triton WR-1339) induced rats. A mixture of leaves is used for the treatment of piles and also as laxative (Khare et al. 2018). Another study conducted by Thiruvenkatasubramanian and Jayakar (2010) on streptozotocin effected rats having diabetes determined that ethanolic and aqueous extracts have the properties of lowering blood glucose. The ash formed from the dried leaves is used for the remedy for cough (Pant and Sharma 2010). The leaf extracts have cytotoxic activity which was also shown by the leaf extract of *B. variegata* against the cancerous cell lines using assay named Sulforhodamine B dye (Mishra et al. 2013).

18.4.3 Roots

Roots of the tree are used to treat dyspepsia, snake poison antidote. They help in cancer prevention (Singh et al. 2019). Roots possess anti-inflammatory (Yadava and Reddy 2003), antihyperlipidemic, antioxidant, and wound healing properties (Singh et al. 2016). The roots are also used in flatulence and dyspepsia (Bhatnagar et al. 1973; Kapoor and Kapoor 1980). The extracts of roots (i.e., aqueous and ethanol) of *B. variegata* possess analgesic effects which may be due to the presence of flavonoids whereas the antiulcer activity may be because of probable association of prostaglandin (Kumar and Rajani 2011).

18.4.4 Buds

The dried buds possess good antioxidant properties (Singh et al. 2016). These are used in the treatment or management of dysentery, piles, worms, eye ailments, liver, and diarrhea (Mali and Dhake 2009).

18.4.5 Flowers

Flowers of *B. variegata* are considered as the rich source of vitamin C. They are used in dysentery, edema (Malhotra and Moorthy 1973), and also have anthelmintic and laxative properties (Badhe and Pandey 1990). They exhibit anticarnigenic activity (Pandey and Agarwal 2009). This study also showed that the flowers have antimicrobial activity and this activity was assessed by using gram +ve and gram –ve. The results revealed the inhibited growth of microorganisms by the use of methanolic extract of *B. variegata* flowers (Kulshrestha et al. 2011).

18.5 Different Uses of *B. variegata* and Its Parts

Apart from medicinal values, *B. variegata* or its parts have many other uses also (Table 18.2).

Table 18.2 Parts of *B. variegata* plant with their uses

Sr. no.	Plant parts	Uses	References
1.	Roots	Mucilage and gums	Deswal and Arora (2015)
2.	Leaves	Used as green fodder for animal feeding; used for mosquito control	Gautam (2012) and Govindarajan et al. (2016)
3.	Seed	Fiber, gum, oil, and tannins in industries	Mali and Dhake (2009)
4.	Flower	Have fragrance, used for making perfumes; used as an ornamental plant, cooked and eaten as vegetable	Mali and Dhake (2009) and Khare et al. (2018)
5.	Bark	Used in dying industries for fabrics	
6.	Wood	Used for making of different agricultural operational tools	Gautam (2012)
7.	Stem	Weak stems fiber is used for rope making	Naeem and Ugur (2019)

18.6 Conclusion

B. variegata (Kachnar) is the medicinal plant which is used for the cure of various diseases and exhibits antiinflammatory, antibacterial, antioxidant, heaptoprotective, hypolipidemic, nephroprotective, wound, antiulcer, antidiabetic, and astringent. The various aspects were discussed about the history, botanical description, medicinal uses, health uses, cultivation, and chemical constituents of *B. variegata*. A variety of chemical constituents were present in *B. variegata* which are responsible for various pharmacological properties, that is, tannins, glycosides, flavonoids, alkaloids, and terpenoids. To combat the emerging health issues, *B. variegata* has the potential to be evaluated further for its medicinal and health properties.

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Pineapple

19

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Abstract

Pineapple (*Ananas comosus*) is an extraordinarily delicious tropical fruit that is also good for your health. Its origin is from South America, and initial Western travelers and explorers named it for its likeness to a pinecone. This well-liked fruit is filled with nutrients, antioxidants, and other valuable compounds, for example, enzymes that can combat soreness and sickness. Edible parts of pineapple and its composites are associated to countless benefits for well-being, including helping in digestion, enhancing immunity, and, among others, speed up healing from surgical procedure. They are particularly rich in vitamin C and manganese, providing respectively 131% and 76% of the daily recommendations. Pineapples are particularly rich in flavonoids and phenolic acids known as antioxidants. Several studies have shown pineapple and its compounds can reduce cancer risk. This is because oxidative stress and inflammation can be minimized. Eating pineapples will reduce the amount of time needed to recover from surgery or exercise. This is primarily due to the bromelain's anti-inflammatory properties. Excessive inflammation is often associated with cancer. Several studies have shown that bromelain can minimize the inflammation, swelling, bleeding, and pain that frequently occur during surgery. It also tends to raise influenza markers of inflammation. Today around 25 million tons of pineapple are produced worldwide, making it the third most eaten fruit after bananas and citrus fruits. At the forefront of its growth, pineapple contributes greatly to the economies of those countries. The special taste makes the food industry invaluable, because it is an integral part of many recipes.

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Ananas comosus · Bromelain · Anti-inflammation · Antioxidants · Vitamin C

19.1 Introduction

Pineapple, *Ananas comosus* (L.) Merr., is characteristically among the varieties in the Bromeliaceae descendants cultivated on a commercial scale for its significant value and is a healthy, super fruit. Pineapples grow in hot and humid tropical climate, as a vegetation that can nurture in usually tepid environment with temperature stretch between 20 °C and 36 °C. It is capable of blossoming at 1800 m higher than sea altitude, even though at the elevated echelons the produce is typically significantly tarter. Cultivation takes place both in the high, humid, and hot areas as well as subtropics. Subsequent to banana and citrus fruits, pineapple typically is the third essential super produce in the world. In 2019, Costa Rica, the tropical nation was the world's leading pineapple cultivator, with an annual cultivation of 26853.12 metric tons. Thailand, South Africa, Nigeria, Brazil, Philippines, Indonesia, India, and China are becoming additional main contributors of pineapple in the world. Being non-climacteric in nature, pineapple fruits ought to be reaped when totally complete to consume. Alterations inside the epidermis shade from olive green to yellowish below the bottom of the produce, a minimal total soluble solid (TSS) content of 12% in addition to a most favorable point of 1% acidity will guarantee a standard essence that is typically suitable for customers.

This appetizing exotic produce can be eaten garden fresh, dried out, processed in jams and juice, in addition to consumed as a source of dietary fiber, bromelain compound, Mg, Cu, Vitamin C, B compound, Ca supplement, β-carotene, plus zinc. Pineapple skin is typically entirely cholesterol- and fat-free and short in Na and calorie utilization. Typically, pineapple fruit is the sole resource of bromelain compound, a protein-degrading enzyme exploited in medicinal marketplace, beverage production, and as an animal protein–tenderizing mediator. The consumption of pineapple fruit presents immense health benefits as it aids the immune structure, shores up the digestive function of protein, improves signs of the frequent cold, and reinforces bone tissues. As of its nutritious qualities, texture, consistency, and ripeness, its utilization is normally ideal at all phases of existence. Similar to several exotic produce, pineapples are susceptible to low temperature damage and subjecting of this fruit to temperature ranges under 12 °C can activate this physical deterioration, depending on the duration of period of storage. As a result, newly harvested fruits ought to be held in reserve at 7–10 °C, as they are considerably not as much susceptible than immature or partially new fruits that ought to be sited at 10–13 °C for no further than 3 to 4 weeks.

19.1.1 History

Pineapples originate from regions of South America, predominantly from Paraguay and Brazil. Laufer (1929) gave an account that inhabitant citizens of America in the plain regions devour this wonderful fruit, and prior to the introduction of Columbus it was extensively circulated in the US, Europe, and the Caribbean nations exclusively (Collins 1960). In 1493, Columbus revealed this marvelous produce on the isolated island these days recognized as Guadeloupe and nominated it “piña,” ascribed it same as pinecone and transported this “exceptional” marvelous fruit to Barcelona, the capital of Spain. The shape and design of the wonderful fruit is similar to its earlier explicit varieties, all of which were approximately or totally seedless. In the era of Columbus, it was extensively utilized as fruit with medicinal properties, in alcoholic beverages, or as a luxury fruit for royals. Its introduction in the America and the deficiency of identifiable disgraceful progenitors of the grown pineapple are supplementary data of this fruit antique (Collins 1960). This wonderful fruit was a primary food of South American treat and ceremony concomitant to ancestral validation.

Pineapple proliferated all around the earth on voyage vessels that consumed it for anti-scurvy, that is, against bleeding gums. The businessmen from Spain brought it to the Philippines first during the sixteenth century. It arrived in Britain during 1660, and started to be cultivated in conservatory during the beginning of 1700 because of its wonderful taste and for decorative characteristics. Businessmen from Portugal introduced this fruit in Indian subcontinent from the Moluccas in 1548, and moreover to the eastern and western shores of African region. The wonderful fruit was being grown during 1594 in Chinese regions and during 1655 in South Africa. During 1819 the “Cayenne Lisse” variety (“Smooth Cayenne”) grown in French Guyana (Southern America) was introduced into Europe and passed on over the world during nineteenth and twentieth centuries (Collins 1951) with various additional varieties, namely, “Singapore” and “Queen’ Spanish.” Initial business ventures were restricted to quite short- shipping routes, due to the succinct shelf survival of new pineapple. As an outcome, Florida, in association with the Bahamas, Cuban cultivars, and Puerto Rico pineapple producers supplied the fruits to North American arcade, the Azores, and the West. At the start of the nineteenth century, a new variety of pineapples had been supplied from West Indies to entire Europe (Loudon 1822).

19.1.2 Production in World and India

According to Food and Agriculture Organization of the United Nations (FAO) data, pineapple stands at the eleventh position in cultivation, with just over 27,402,956 tons produced in 2017.

India is the sixth highest world’s pineapple growing nation, followed by Nigeria and China. The leading 10 producer countries, shown in Table 19.1, represent almost 74% of world’s harvest, but have got transformed very little since the 2000s.

Table 19.1 List of 10 leading nations for pineapple cultivation, 2017

Nation	Production (thousands of metric tons)
Costa Rica	26,859
Brazil	2483
Philippine	2458
Thailand	2209
Indonesia	1837
India	1571
Nigeria	1420
China	1386
Mexico	771
Columbia	643

Table 19.2 Top 10 fresh pineapple exporter countries, in tons, 2017

Country	Production
Costa Rica	2,126,929
Philippines	461,856
Panama	67,038
Ecuador	57,380
Honduras	51,258
Mexico	41,271
Côte d'Ivoire	33,976
Ghana	33,175
Guatemala	25,091
Malaysia	23,585

Colombia, Mexico, China, India, and Philippines have got noticed for a consistent harvest boost since 2000. Nevertheless, the progression has been even more irregular for Thailand and Brazil, with a sharp fall between 2006 and 2009, and progress resuming from 2010. Finally, Costa Rica, Nigeria, and Indonesia have been developing continuously and substantially between 2010 and 2017. Table 19.2 represents the top pineapple exporters of the world.

Costa Rica sticks out due to the advantage of its expertise. The global number one producer is undoubtedly the commanding exporter nation since it markets almost all of its production fresh and of high quality, with the leftover targeted at the juice sector. On the other hand, the Philippines merely exports around 20% of its production fresh and of high quality, the leftover 80% is primarily directed to processing. Mexico is certainly in identical circumstances, though for substantially lower amounts. This implies that the primary producer nations, apart from Costa Rica, send out their production for regional utilization, and above all processing and refinement. This is the case with Thailand, the Philippines, China, and Indonesia, which possess an effective support over the refined items market (jam, plain, or concentrated juice) which rules the Asian supply.

19.1.3 Botanical Description

Pineapple, *Ananas comosus* (L.) Merr., out of numerous well-known tropical fruits, is only individual fruit famous for its unique, appetizing flavor and remarkable exterior. Taxonomically, this fruit plant is usually ordered as below:

Kingdom:	Plantae
Subkingdom:	Tracheobionta
Super division:	Spermatophyta
Division:	Magnoliophyta
Class:	Liliopsida
Subclass:	Zingiberidae
Order:	Bromeliales
Family:	Bromeliaceae
Genus:	Ananas Mill.
Species:	*Ananas comosus* (L.) Merr.

It is an exclusive type present in the Bromeliad family that is mainly cultivated for profit through its fabulous fruit produce. The Bromeliad family have in total 56 genera and approximately 2600 diversities. The vintage of this marvelous fruit has been confirmed due to the sustenance of elite varieties, which are nearly or entirely seedless, lack of discernable appalling antecedents, and widespread scattering from their very likely middle of source (Coppens d'Eeckenbrugge et al. 2011).

This wonderful fruit is a herbaceous, perpetual monocot with Crassulacean acid metabolism (CAM) (Anon 2015). The progress of plant in tallness is from 0.8 to 2 m with the same extent in girth, based typically upon the leaf dimensions, mostly on leaf length. The roots, stem, shoots, leaves, peduncle, the complex manifolds of super fruit, and the crown are chief morphological constituents. The complex splendid fruit mainly comprises of the inflorescence, containing abundant florets which are amalgamated to a syncarp. The plant of pineapple imparts two kinds of roots: (a) Central roots that are just observed in fairly small sprouting baby plants and perish rapidly after sprouting; and (b) Adventitious roots, which are perceived beneath the bottom of the shoot, that enlarge and develop into an efficient subterranean root with merely bizarre root subdivisioning. Beneath proper rising environment, the roots may scatter up to 1.2–2.1 m sideways with a depth of 0.85 m. The massive number of adventitious roots amplified out of developed crown generally surpass the shoots in length, and the extent of genesis on positions is connected to take surplus heaviness. Auxiliary roots are positioned in the leaf axils. During dry growing conditions, these auxiliary roots of the pineapple plants facilitate it in abrupt assimilation of water and nourishment elements. Unlignified white cellular matter at the apex of the auxiliary roots allow the water and favorable nutrient assimilation. The trunk comprises of internodes and nodes, is typically 28–55 cm in length, 2.5–5.4 cm broad near the base, and 5–8 cm on the "hit" which is the highest point. At the central part of the trunk, a rosette of prolonged linear leaves is typically subtle there. The aerial shaft or stem is typically erect and upright, as the exterior of the concealed parts are based upon the resources employed for developing. If created from a slip, subsequently it is characteristically and clearly curled, because the trunk of these propagules are comma-shaped, and to a less extent curled after forthcoming from shoot and straight when approaching from a head (Coppens d'Eeckenbrugge et al. 2003). A slip raises on the fruit peduncle just beneath the produce and begins appearing around 30 days immediately after blossom set stage. Cultivar and time of year significantly affects the amount of slips created. Base shoots build upward while the superb fresh fruits push all the way to ripeness. On the stem, the foliage is waxy and specifically coiled. The band-like protracted sharp green or red-lined leaves are often spiny at tips and normally stand razor-sharp, with up-coiled thorns on the borders. Numerous cultivars, for example "Smooth Cayenne" exhibit an unfinished or entire lack of thorns on the leaves. The foliage has trichomes on the bottom region. Trichomes are minute, resembling fur, and enclose the stomata (70–80 stomata/mm) to additionally constraint excess moisture diminution by elevating the width on peripheral layer. The fully developed plant features 70–80 leaves, the adolescent in the center, and the aged on the exterior.

19.1.4 Nutrients and Environmental Conditions

Fruit advancement from bloom initiation (compelling) to fruit maturing needs 140 to 300 days, based on atmospheric warmth as effected by coordinates, height above sea level, and period of year (Bartholomew 2013). Growth progress dies down below 10 °C and is typically controlled over 35 °C. There is commonly no flower abscission, and sneering of the style is excluded, androecium and corolla are also felt out of withering, the whole blossom develops parthenocarpically to a fruit similar to fruitlet. As explicit fruitlets progress from the blossoms, they merge equally and form cylindrical pattern resembling a cone, 30 cm in length or even further and 0.8–3 kg in mass (Teisson 1973). The fruit of pineapple is normally seedless and is termed as syncarp. Nowadays, this fruit is certainly present in nearly all the humid and hot to sub-humid regions of the world. Production of fruits (kg/ha) is extremely changing and fluctuate from 37,100 tons (African Sudan) to 466,600 tons (Island of Australia). This immense disparity in production is generally for the reason that minute farmstead in nations that utilize the most effectual technology, skill, knowledge, and expertise have a propensity to acquire higher yield than carrying out cultivation on enormous plantations, making utilization of the similar technology, but usually holding elevated field shortfall. Drought tolerance is one of the properties of the pineapple plant, because it is a xerophyte with a leaf construction that has a feature of water-retentionregion, and epidermis–hypodermal-covering composite and parenchyma that creates its drought resistance. Pineapple cannot endure freezing temperature ranges, and root and shoot development does not take place at or below 7 °C (Sanford 1962).

Plant replicas centered on temperature units signify a basal temperature array of 8.3–15 °C, and among them there is typically negligible advancement of plants and fruits (Fleisch and Bartholomew 1987; Zhang et al. 1995; Dubois et al. 2010). Minor standard temperature ranges dim down the vegetation development pace; modify the design of Co_2 separating among foliage, fruit and stalk; and lengthen the maturing habit and alterations in the pineapple fruit structure (Py et al. 1987; Malézieux et al. 1994). From the time when plant and fruit development are powered by surrounding temperature, built-up warmth models can be utilized to forecast raises in plant heaviness at the time of vegetative expansion in addition to the improvement just before wonderful fruit mellowness (Fleisch and Bartholomew 1987; Fournier et al. 2010; Dubois et al. 2010). Many industrial pineapple plants are cultivated in locations with elevated insolation. At the time of photosynthesis, leaf of a pineapple is usually implicated to finish up being inundated below 25% of complete daylight, and thus high luminosity is positively desirable to maintain the elevated amounts of efficiency discovered in industrial farms. Fruit heaviness is considerably related with high luminosity from sowing to harvesting and the lesser fruit heaviness is undoubtedly connected with lower luminosity ascribed to a making of poorer plant mass (Bartholomew and Malézieux 1994). For every 20% drop in sun energy rays, harvest drops about 10%. Intense sun rays at the time of pineapple fruit ripeness predominantly can trigger sunlight-scorching of fruits. Pineapple is usually cultivated in nearly each sort of land located in the humid and sub-humid conditions including peat loam, course grimy earth, extremely cumulative clayey earth soil, and extremely rocky earth soil. The best land form is in generally a supple sand or well-cumulative soil surfaces consisting of a suitable depth of 100 cm approximately and with immense drainage to avert water haulage and disarray of root (Hepton and Bartholomew 2003). Sound cumulative earth surface, having enormous water-retention potential, will also reduce the need for supplementary irrigation in regions where precipitation is not homogeneously scattered all through the year. Standard pH array for pineapple is typically from 4.5 to 5.6 (Hepton and Bartholomew 2003) and the tart surface reduce origin and heart rot set off by *Phytophthora* spp. Potassium (K) and nitrogen (N) are the two vitals utilized in the standard magnitudes to the growth of pineapple. The cumulative amount of nitrogen utilized ranges from about 4 to 8 g/plant (330–630 kg/ha at a width of 80,000 vegetation/ha). However, lesser amounts would be utilized when vegetations are diminutive, or growth is slow, that is, in chilly climate. The Fe/Mn quantity is normally more necessary than the concentrations of other advantageous nutrients only. Ferrous sulfate foliar sprays are used to control Mn-stimulated iron-deficiency disease like chlorosis at up to 17 kg/ha per plan. Yearly precipitation in regions where pineapples are grown can range from <600 mm to >3500 mm. However, the standard precipitation, if well disseminated all through the yield schedule, for immense industrialized expansion with no irrigation sums from 1050 to 1550 mm. Pineapple leaf construction is best suitable for the gathering of considerable amount of dew concentration on leaves and gushes up into a leaf whorl. Leaf trichomes which are underneath the leaf vortex are the places where water is normally assimilated (Sakai and Sanford 1980) and in reaction to wetness and nourishment in leaf axils, axillary root base are developed. Irrigation enables 12-month-round growth and maintenance, with plants reaching adequate size when expected to make fruits of suitable size at planned harvest and distribution. Drop/drip irrigation of pineapple vegetation formulate the effective consumption of water and aids to lessening of wild plants (weed) or other unnecessary vegetation challenges as the watery territory of earth is generally diminished. Trickle irrigation also facilitates fertilizers, manures, and other beneficial compounds to become utilized at the root structure after growth and uphold with enhanced effectiveness, so that protection and produce are improved. Overhead self-propelled expansion sprayer irrigation system and touring guns hold reduced capital expenses and are often exploited where the necessity for irrigation is typically erratic. Hence, the quantity of water used to grow pineapple is low, roughly 50 mm/ha/month (Hepton and Bartholomew 2003).

19.2 Antioxidant Properties

Pineapple offers many useful properties, consisting of antioxidant activities. Plants generate several toxic-eliminating and radical-reducing substances, enzymes, and nutrients as antioxidant defense to uphold regular development and activity (Pandhair and Sekhon 2006). Elevated ingestion of protective foods (fruits and veggies) has been concomitant with the possible therapy for various acute and chronic disease conditions, like cardiovascular sickness, malignancy, etc. (Leifert and Abeywardena 2008; Bajpai et al. 2009). The compounds from plants aiding toward the betterment of individual wellness involve the anti-radical substances, especially polyphenols. Primarily pigments in plant life are flavonoids, which also perform as antioxidants. Many pathological human illnesses including malignancy, heart and brain sicknesses such as cardiovascular diseases (CVDs), and cerebral illnesses which are the outcome of radicals peroxides are responsible for deterioration of fats, nucleic acids, substances having proteins, and unsaturated fats (Choi and Lee 2009). Feasible technique in fighting such sickness is typically to enhance our body's anti-radical defense. Enormous uptake of fruits and vegetables loaded with anti-radicals has been associated with a reduced occurrence of such chronic sicknesses (Bajpai et al. 2009).

Pineapple, *Ananas comosus* L., Merr., also considered as a vital tropical fruit, is generally consumed in several parts of the world mostly as refreshing fruits, in juice forms, jams, jellies, and dried-out goods. It offers a soaring nutritive value and is typically a rich reserve of vitamin A, vitamin B, and vitamin C as well numerous nutrients such as calcium, iron, and phosphorus. Despite the fact that there are quite a few assessments on the anti-radical properties of pineapple in correlation to numerous other fruits (Gardner et al. 2000), they focus on just one or two variables, and not are actually very well informed nor do they suggest feasible elements/procedures to enhance anti-radical properties. Numerous investigations have discovered that the preponderance of the anti-radical activity might be from complexes such as anthocyanins, catechins, and various other phenolics like flavonoids, isoflavones, flavones, etc.

19.2.1 Fruit

Bioactive chemical substances are additional dietary ingredients that characteristically occur in minute magnitudes in foods. These chemical substances are closely connected by means of their positive results on human wellness, on heart diseases – CVDs mostly, malignancy, and on the reduction of aging (Kris-Etherton et al. 2002). These constructive consequences are mainly accredited to their dominant anti-radical activity and free substance–scavenging capability (Scalbert et al. 2005). Several bioactive phenolic chemical substances include flavonoids, phytosterols, glucosinolates, carotenoids, phenolic acids, monoterpenes, and extremely dynamic complexes like vitamin C (Ayala-Zavala et al. 2011). The primary anti-radical substances reported in pineapple pulp are vitamin C, catechol, catechin, carotenoids, etc. (Kongsuwan et al. 2009). In addition, by-products of pineapple fruit, for example peels and shells, are important sources of conjoint phenolics and vitamin C (Larrauri et al. 1997). Moreover, fruit of pineapple is positively considered a rich contributor of the healing enzyme bromelain, a multifaceted compound together with proteinases and additional proactive substances (Maurer 2001). (Table 19.3)

19.2.1.1 Ascorbic Acid

Skin of wonderful fruit possesses enormous concentration of ascorbic acid, a natural water-soluble antioxidant or anti-radical that might reduce and arrest unpleasant medical situations. Skin of this wonderful fruit consists of 47.9 mg/100 gm of total vitamin C (ascorbic acid as well as dehydroascorbic acid) per 100 g of fresh mass, totaling about 34% of the whole anti-radical power of pineapple (Diplock 1994; Szeto et al. 2002). Nevertheless, processing of fruit juice of pineapple entails diverse processing measures.

19.2.1.2 Phenolic Compounds (PC)

All chemical substances inside pineapple fruit, phenolic compounds, were accepted as being the principle bioactive components with regard to overall health benefits. Phenolic molecular content of pineapple fruit appears to have been stated in numerous investigations, and this content changes with wide selection, cultivating environment, maturity date, plus extra geographical characteristics (Gorinstein et al. 1999; Sun et al. 2002). Most of the phenolic compounds in pineapple fruit remains (mush, kernel, and peel) are often documented as grander compared to the skin. Furthermore, various scientific studies revealed that phenolic material shows a positive interaction associated with anti-oxidant activity (2,2-diphenyl-1-picrylhydrazyl (DPPH) and ferric reducing antioxidant power (FRAP) assays) associated with the pineapple ultra-fruit (Kongsuwan et al. 2009). Specifically, ferulic acid, protocatechuic acid, luteolin-7-O-glucoside, chlorogenic acid, and myricetin are distinct phenolics found inside pineapple, plus these are generally proposed to be accountable for their organic as well as helpful impacts after the consuming of the fresh fruit (Fu et al. 2011).

Table 19.3 Antioxidant contents (mg/100 g FW) of pineapple genotypes

Genotype	Gallic acid	Catechin	p-Hydroxybenzoic acid	Chlorogenic acid	Vanillic acid	Epicatechin	Coumaric acid	Ferulic acid	Erucic acid	Myricetin	Cinnamic acid	β-carotene
New Phuket	0.076	8.068	0.039	0.002	–	0.789	–	0.005	3.544	0.010	–	0.172
Fresh Premium	0.030	15.238	0.048	0.001	–	0.441	0.016	–	5.910	–	–	0.146
Ripley	0.048	12.224	0.031	0.003	–	0.440	0.022	0.014	–	–	0.003	0.190
Tainung 17	0.014	4.357	0.021	0.003	–	1.015	–	–	0.248	0.038	0.007	0.244
Shenwan	0.030	2.400	0.016	0.019	0.008	–	–	0.010	2.663	0.033	–	0.031
Smooth Cayenne	0.054	6.333	0.057	0.004	–	0.370	–	–	3.820	0.008	0.008	0.115
Chenhuang	0.040	5.333	0.020	0.006	–	–	–	–	8.277	0.054	0.003	0.030
Comte de Paris	0.028	7.728	0.052	0.012	0.007	0.665	0.025	0.011	0.084	0.102	0.001	0.052
MD-2	0.024	8.094	0.068	0.006	0.013	0.214	0.011	0.020	0.136	0.071	0.005	0.040
Red	0.031	28.615	0.016	0.003	–	0.088	–	0.012	7.057	0.030	–	0.037
Pineapple Jasopina	0.043	9.170	0.048	0.001	0.013	0.690	0.026	0.007	8.489	–	0.002	0.208

19.2.1.3 Carotenoids

Carotenoids are naturally high and substantive pigments that possess additionally acquired immense attention due to both the pro-vitamin A and lipophilic antioxidant functionality (Liu 2004). All types of carotenoids identified inside pineapple possess in reality a considerable volume of epoxide groups. These groups tend to be rapidly isomerized toward furanoid types when in acidulent state, however, not really within a non-acidic conditions (Singleton et al. 1961). Vital carotenoids spotted inside pineapple are 50% violaxanthin, 13% luteoxanthin, 9% β-carotene, and 8% neoxanthin, also lesser amounts of auroxanthin, cryptoxanthin, hydroxyl–αcarotene, lutein, plus neochrome (Bauernfeind 1981). Moreover, pineapple by-products are also essential resources among these kinds of compounds. Additionally, the existence of lutein plus β-carotene inside pineapple core has been stated (Freitas et al. 2015).

19.2.1.4 Bromelain

Bromelain, type of a proteolytic chemical inside pineapple fresh fruit, is quite revealed as authentic, most beneficial, and even examined bioactive chemical. Its properties were examined since 1884 (Devakate et al. 2009) and also had been previously revealed during 1891 by Marcano (Balls et al. 1941). Bromelain is a water extract which comprises as, at lesser levels, a complicated combination of proteases plus non-protease compounds, including several other molecules. The proteolytic enzymes are sulfhydryl proteases, as their proper enzymatic activity requires a free sulfhydryl group of cysteine part chain. These enzymes play a crucial role in cellular matrix proteolytic modulation in countless biological endeavors (Soares et al. 2012). It is mostly found in stem, hence called stem bromelain with a nomenclature EC 3.4.22.32 and additionally in fresh fruit having nomenclature as EC 3.4.22.33. Pineapple by-products contain a limited quantity of bromelain.

19.2.2 Juices

Pineapple fresh fruit extract is usually a significant acidic product which is generally safeguarded by aseptic handling through hot stuffing. In diverse wrapping designs and sizes, the pineapple fruit drinks are successfully filled aseptically. The primary factor in the use of aseptic wrapping as well as handling with regard to fruit crush from pineapples is its good standard and high nutrient and sensory preservation character. Aseptic packaging includes the commercial aseptic product being filled in clean product packaging according to aseptic environment (Robertson 2016). High-temperature short-time (HTST) treatment solutions are customized to sanitize the goods in aseptic product packaging as well as handling. In glassware and metallic element packaging, the enhancement in the barrier attributes of materials utilized in aseptic product packaging has attained the consequent shelf-life of pineapple fresh fruit juice. That is why, product packaging systems and aseptic wrapping systems are crucial to keep the freshness and maximum excellence of pineapple commodities around the shelf-life established. The routinely employed aseptic pineapple extract product packaging means include cartons, pockets, as well as containers. Due to its exceptional resource for vitamin supplements, phenols, organic and natural acids and carb supply, the most popular construction for the carton system is a cardboard laminate comprising of polyethylene (PE), paper, lightweight aluminum. Carotenoids are the foundation for the distinctive shade of the fresh fruit juice, although the flavor emanates from a complicated combination of chemical substances. Pineapple fresh fruit juice is popular and prevalent with human population and it is promptly transforming into a favored fresh fruit good since it is on display in supermarkets, grocery stores, and fruit markets. Pineapple drinks contain ferulic acid, luteolin-7-O-glucoside, myricetin, ascorbic acid, protocatechuic acid and chlorogenic acid, lutein, cryptoxanthin, hydroxyl-α-carotene, auroxanthin and neochrome, violaxanthin, luteoxanthin, β-carotene and neoxanthin, bromelain, salicylic acid, tannic acid, trans-cinnamic acid, and myricetin and p-coumaric acids, which in turn might be accountable for the elevated free radical cleansing activity. These attributes are very significant because they have been associated with an advantageous impact upon human being wellness including safeguard toward cardio issues, some kinds of malignancy, diabetic issues, neurodegenerative ailments, hypertension, and control of blood hormonal insulin levels just after intake of meals.

19.2.3 Peel

There are five crucially important polyphenolic molecules within peel: catechin (Fig. 19.1), gallic acid, epicatechin, ferulic acid, and ascorbic acid (Fig. 19.1). A natural acid gallic acid (Fig. 19.1), also known as 3, 4, 5-trihydroxybenzoic acid, is located in witch hazel, tea leaves, gallnuts, oak bark, sumac, berries, and many plants. $C_6H_2(OH)_3COOH$ is its compound formula. It is commonly used in the drug sector. The hallucinogenic alkaloid mescaline, also called 3, 4, 5-trimethoxyphenethylamine, can also be used to synthesize gallic acid. Gallic acid salts and esters are known as gallate. A commonly occurring plant phenol, gallic acid (GA) was even seen to be an effective free radical cleansing compound in colloids or lipid systems (Madsen and Bertelsen 1995; Nakatani 1992) and anti-

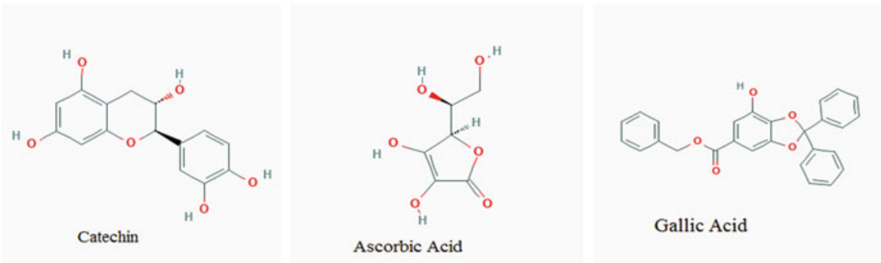

Fig. 19.1 Structure of catechin, ascorbic acid and gallic acid

malignant display. Gallic acid is also suggested to attenuate the rancidity developed in lipids by lipid peroxidation and spoilage in manufactured products, cosmetics, as well as products wrapping goods.

The product is practically as effective as the Trolox tocopherol analogue, sometimes more reliable compared to several water-soluble antioxidants, particularly ascorbic acid (Cholbi et al. 1991). Gallic acid is discussed lately as providing the cytotoxic impact upon separated hepatocytes (Nakagawa and Tayama 1995). Sakagami and Satoh (1997) confirmed the fact that ascorbic acid and gallic acid functionality as being pro-oxidant in human being glioblastoma cells for the inducer of apoptotic cellular destruction. Inoue and Kawanishi (1995) pointed out that gallic acid might stimulate cellular destruction in HL-60. As a result, this research assessed the pro-oxidant and free radical cleansing attributes associated with gallic and ascorbic acid utilizing deoxyribose assay, free radical scavenging, and ferrous ion chelation; as well as influence on individual's lymphocytes employing single cell serum electrophoresis along with oxidative deoxyribonucleic acid damage.

Catechin is usually a free radical cleansing flavonoid that typically appears within woody vegetation as (+) -catechin and (−)-epicatechin (cis) types, antioxidant flavonoid. Ferulic acid is an acid consisting of methoxy-holding trans-cinnamic acid and hydroxy substituents correspondingly on the phenyl ring at locations 3 and 4. It has an antioxidant function, a matrix material of matrix-assisted laser desorption/ionization (MALDI), a plant metabolite, an anti-inflammatory agent, an apoptosis inhibitor, and a cardioprotective agent. It is a ferulate conjugated acid. Ferulic acid is quite a very adequate phytochemical phenolic located within the wall membrane of plant tissues. Trans-ferulic acid is usually a phenolic compound that small intestine will soak up and excrete via urine. It is probably the most comprehensive plant phenolic acid, ranging from 5.5 g/kg in overall whole wheat bran to 9.5 g/kg inside sugar beet mush as well as 55 g/kg within corn grain. It mainly appears within the plant seed and also in leaves each within the (rarely) open form and covalently fused along with lignin and various other biopolymers. It is normally located within the cellular wall surface as ester crossover links together with polysaccharides, such as grass arabinoxylans, green spinach pectin, refined sugar, and bamboo xyloglucans. It can also interface with proteins. Because of its phenolic core and stretched side chemical chain coupling (carbs as well as protein), it develops swiftly a resonance stable, free radical phenoxy which in turn is liable for its compelling free radical cleansing functionality. Curcumin and ferulic acid supplementation of meals is seen as a dietary strategy to lessen oxidative destruction as well as amyloid pathological ailments in Alzheimer's disorder. Ferulic acid is often a widely utilized plant ingredient that actually emanates from the metabolic process connected with phenylalanine along with tyrosine. Methanol was used to extract pineapple peels, and the removal production has been 25.95% along with the pureness of 32.98 mg gallic acid equivalents/grams. Li et al. (2014) removed the vital polyphenolic molecules found in fruit peels of pineapple consisting of catechin (59.51 mg/100 g dried retrieves), epicatechin (51.00 mg/100 g), gallic acid (32.76 mg/100 g), as well as ferulic acid (20.50 mg/100 g).

19.2.4 Waste

Pineapple waste material is a result of the processing of pineapples and consists mainly of residual pulp, peels, and skin. Pineapple waste materials can be classified as pineapple on farm waste (POFW) material along with pineapple processing waste (PPW) material. POFW is composed of leaves, stems, and roots. After pineapple farming, leftovers are processed in farms. Ananas may perhaps be handled in a variety of techniques, including cutting, mushing, and making juice. The primary processing phase incorporates crown stripping accompanied by synchronous elimination of peel-off as well as core. Every one of these methods generates fluctuating proportions of pineapple processing waste material. In addition to peels, crown, and core, the fruit juice organizations produce fluid waste products along with pomace. Pomace records 30% of the pulp when it is assumed that the processing recovery is 70% secondary metabolites such as polyphenols subsist in plant tissues (Middleton et al. 2000). Fresh fruit waste tends to have plenty of antioxidants within them in comparison to the whole fresh fruit (Ayala-Zavala et al. 2010). Polyphenolic antioxidants present in plants end up being utilized meticulously within medicinal drugs as well as skin care formulations. Phenolic antioxidants are the vital classification of phenolic components, flavonoids, as well as tannins. Polyphenols acquire plenty of overall health benefits, particularly antioxidants, antiallergy or anti-intolerance, antimicrobic, anti-inflammatory as well as anti-thrombotic results. Quercetin, catechin, plus kaempferol are some of the extensively examined molecules which have always been identified to lessen the possibility of serious medical conditions particularly numerous types of cancer tumors, polygenic disorder challenges, coronary heart as well as obese conditions (Rasouli et al. 2017). Epicatechin, gallic acid, catechin, and ferulic acid have actually been distinguished as primary polyphenolic substances within pineapple skin (PPW) (Li et al. 2014) (Hossain and Rahma 2011). During their study, the output of polyphenols in pineapple skin was maximum after methyl alcohol was adopted to be the removing solvent. Overall extractable molecules were produced 22.5% in methyl alcohol, 5% in ethyl acetate, and 4.4% in a standard water extract. Methyl alcohol extract has maximum portion of phenolic substances (52.1 ± 0.2 mg/g) backed via the infusion with ethyl acetate (13.8 ± 0.1 mg/g) and also the take out from water (2.6 ± 0.1 mg/g). In alternative analysis, the total phenolic content of pineapple peels is ascertained up to 7.88 mg gallic acid equivalents (GAE)/gram dried mass (Li et al. 2014) once removed using methyl alcohol. The arrangement of DPPH radical removes capabilities of 1 mole regarding the polyphenolic chemical substances contained in pineapple peels had been presented to be in the arrangement of ferulic acid $<$ catechin $=$ epicatechin $<$ gallic acid (Li et al. 2014). A phenolic acid, ferulic acid discovers appealing utilization in the skin care and meals establishments (Ou and Kwork 2004). This ferulic acid could additionally be changed into vanillin (Lun et al. 2014), which in turn has an exceptional industrial worth because the fragrance as well as essence segment is anticipated to encounter massive boost in amounts having a compound annual growth rate (CAGR) of 6.0% between 2018 and 2026 in the international market. The procedure includes ferulic acid bioconversion to vanillic acid and vanillin.

19.3 Chemical Substances and Their Characterization

19.3.1 Volatile Chemical Substances in Numerous Portions of Pineapple Fruit

The particular detection would be carried out through matching up its MS spectra along with those existing within a data bank of citation (NIST 2005). Mush/pulp and kernel/core examination exhibited 44 fickle substances, 18 of which had been esters, 17 happened to be terpenes, as well as a few happen to be alkenes. The entire mush fragrance density has been 484.95 μg/kg; the largest density regarding ethyl hexanoate was (106.21 μg/kg) accompanied by ethyl 3-(methylthio) propanoate (91.21 μg/kg). It identified 31 volatile compounds in the pineapple core. The total core concentration was 284.16 ug/kg; ethyl hexanoate ended up being the primary chemical (48.42 μg/kg), followed closely by ethyl 3-(methylthio) propanoate (42.67 μg/kg). In a nutshell, both in pineapple pulp and core, 21 forms of fickle substances had been revealed that consisted of 11 esters, 7 terpenes, 1 lactone, 1 aldehyde, and 1 alkene.

19.3.2 Assessment Regarding Types and Components of Aroma Evaporable Chemical Substances Within Pineapple

Outcomes coming from the assessment concerning evaporable fragrances revealed esters as well as terpenes as the majority evaporable chemical substances both in mush as well as in pineapple core as well as their proportion symbolized 84.07% plus 13.5% in mush as well as 54.5% plus 30.33% in core. In mush the ester values have been one and a half instances greater than in core, although in mush the terpene amount was actually a lot less than in core. Esters were responsible for 74.75% of entire pineapple fruit fragrance generation, which in turn involved terpenes (19.79%), alkenes (3.67%), aldehydes (1.31%), ketones (0.78%), and lactones (0.70%) (Wei et al. 2011).

19.3.3 The Typical Fragrance Substances of Pineapple

Within pineapple mush seven typical fragrance substances had been identified, of which ethyl 2-methylbutanoate possessed superior aroma activity value (1693.33), accompanied simply by ethyl butanoate, ethyl hexanoate, decanal, DMHF, ethyl 3-(methylthio) propanoate, and ethyl (E)-3-hexenoate, in falling arrangement. Four typical fragrance substances have also been revealed within the core of pineapples. Ethyl hexanoate influenced the core fragrance in the biggest extent, accompanied by ethyl 3-(methylthio)propanoate, nonanal as well as decanal based around its aroma activity value.

19.4 Conclusion

Pineapple is an exotic organically grown product, which comprises of a proteolytic bromelain complex which assists alongside necessary protein assimilation. Provided it is bromelain content, pineapple can easily avert blood cluster arrangement. Supplements of pineapple include calcium mineral, blood potassium, dietary fiber, as well as ascorbic acid. It offers reduced fat plus minimal bad cholesterol content. Ascorbic acid and minerals is the significant standard water-solvent compound when it comes down to prohibition of malignant tumors in the human body, in opposition to free radicals which assault as well as damage standard tissues. It is also a significant supply of vitamin supplements B1, B6, copper, and nutritional dietary fiber. An amazing amount of ascorbic acid is usually supplied by pineapples, the widely acknowledged melanoma reduction compound that actually defends as well as elevates the human body from free severe damages plus elevates the invulnerable design. Ascorbic acid really helps to develop and also cure significant cellular material and assists to repair wounds. The human body utilizes ascorbic acid to aid process excess fat as well as cholesterol levels, to take in iron as well as to blend essential amino acids and collagen. Collagen is one of the essential skin, ligament, and bone squares in the structure. Too much vitamin C lowers the severity of colds and contaminations. The natural product is used to make jams, cheddar, jelly, syrup, squash, juice, ready-to-serve (RTS) beverages and beverages of amazing demand in the national and universal brands.

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Quince

20

Gulzar Ahmed Rather, Mohd Yasin Bhat, Siva Sankar Sana, Aarif Ali, Mir Zahoor Gul, Anima Nanda, and Musheerul Hassan

Abstract

Quince (*Cydonia oblonga* Mill.) is an important deciduous fruit tree species, belonging to the Rosaceae family. Although it is native to the western Asia region, it is also grown in several other parts of the world. As quince is a temperate fruit, it can grow only in few regions of India, especially Jammu and Kashmir and Himachal Pradesh. The fruit possesses a plethora of medicinal properties because of its varied chemical composition. As a nutritional and dietary food source, it contains carbohydrates, fat, proteins, fibers, vitamins, and minerals. The quince fruits are also known for their distinctive flavor, fragrance, hardness, and acerbity. They are known to have astringent, carminative, antivinous, and laxative properties. Quince is also known to contain medicinally important metabolites such as phenolics, flavonoids, carotenoids, organic acids, terpenoids, tannins, and other volatile compounds. These metabolites in

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fruits, as well as other organs, are accountable for many important medicinal properties like antioxidant, antidiabetic, anti-atherosclerotic, anti-inflammatory, anticancer, antiallergic, hepatoprotective, aphrodisiac, antidiarrheal, antidepressant, diuretic, etc. Besides this, they are also used in the management and cure of hepatitis, influenza, skin abrasions, ulcers, constipation, sore throat, respiratory tract, and urinary problems. Quince can be considered as an ancient nourishing fruit with a copious potential with health-promoting roles and medicinal properties.

Keywords

Quince · Antioxidant · Medicinal properties · Polyphenols · Antiallergic

20.1 Introduction

***Cydonia oblonga* Mill.**
Kingdom Plantae
Division Magnoliophyta
Class Magnoliopsida
Sub-class Rosidae
Order Rosales
Family Rosaceae
Subfamily Maloideae
Genus Cydonia
Species *Cydonia Oblonga*

Cydonia oblonga Mill. (Quince) is the only species of the monotypic genus Cydonia of the Rosaceae family. There exist, however, several subspecies and forms which have been described (Duarte et al. 2014). Apart from being commonly called quince in the English language, it is popular by several common names in various regions of the world. In the Indian Ayurveda (Sanskrit) system, it is known by few names such as Amritphala, Pataalaa, and Imbitikaa. The other common names in different languages are as Behi (Urdu/Hindi), Wen po (Chinese), Ajva (Russian), Ayva (Turkey), Al Sefarjal (Arabic), Quitte/Quittenbaum (German), Cognaisser/Coing (French), Marmaelo (Portuguese), Kvitten (Swedish), Marumero (Japanese), Membrillero (Spanish), Shul (Persian), Bum Choonth (Kashmiri) etc. (Lopes et al. 2018).

20.1.1 History

The core center of origin of quince is the Transcaucasia region, which includes countries like Iran, Armenia, Azerbaijan, southwest Russia, and Turkmenistan. Quince is a native plant in rocky foothills and woodlands of Western Asia (Middle East). Due to its survival capability and tolerance in a variety of climates and latitudes, it has spread from its center of the origin or native area to the countries up to the Himalayan mountains in the eastern side extending to China, while as in the west, it has spread to most of the Europe and Mediterranean region (Hummer et al. 2011; Ashraf et al. 2016). As per guesstimates of some botanists, its cultivation for commercial gains began especially in the Transcaucasia region approximately around 4000 BC. In the Middle East, it has historical legends associated with it, and is believed to be the "fruit of temptation" in the Garden of Eden. The ancient Hebrew Biblical name for quince implies as "Golden apple." The ancient Greeks and Romans considered quince as their favorite pome, particularly for its medicinal qualities. It was cherished as a symbol of love, happiness, and prosperity commonly offered in honor or tribute to the Goddesses Aphrodite (Greek) and Venus (Roman) (Davidson 2014). During the middle ages, the Arabs also valued and recognized this fruit very much, owing to its numerous medicinal virtues. To mark their high esteem, it was frequently served at tables of royal families and aristocrats, who consumed it at banquets and extravaganza culinary events. It is believed to have come to India from the Arabian region in the eighth century during a time when extensive trade was going on between two regions. The tree was brought to America by European settlers, and commercial cultivation for fruit is carried out in many states of the US, chiefly including California, Pennsylvania, and Ohio, etc. In the Mesopotamia (Iraq) region, its cultivation and flourishing history are older than that of apple (4000–5000 BC) since these plains are too hot for apple (Abdollahi 2019). Quince fruit was also revered as a fruit of good omen in ancient Greece since it was presented as a gift to the bride on the day of the wedding to symbolize fertility. A law was even passed in archaic Greece (Athens) by the Solon (630–560 BC) making it compulsory for the newlyweds to eat the quince fruits before consummating their marriage. Theophrastus (371–287 BC), a Greek philosopher and popularly known as Father of Botany described this plant in his "Enquiry into Plants" (*Historia Plantarum*) and noted that it was one of the fruiting plants that do not come true from seed. Pliny the Elder (23–79 AD) in his "Natural History" has also mentioned a few types of quince and revealed some of their valued and beneficial characteristics (Hummer et al. 2011). Quinces are presumed to spread in the thirteenth century to Britain from France, where they were prevalent. Emperor Charlemagne after recognition of their worth passed an order in 812 AD to plant them in the royal garden. The popularity of this plant achieved great heights along with pomegranates and oranges since they were considered as protective against general plagues and the Black Death in the fourteenth century (Hunter and Kelly 2014).

20.1.2 Production

Quince although regarded as the desired crop globally, with both dietary and non-dietary benefits, does not compete commercially with other favorite fruits like lemon and orange. Quince is cultivated in many countries for using rootstock of dwarf pear and loquat. The quince shows tremendous performance in fertile humic soils (2–3% humus) with slightly acidic pH (6.5) and having enough water-retention

Table 20.1 Top ten quince producer countries in 2018 (UN FAO STAT 2018)

Rank	Country	Area harvested (Hectares)	Quince production (MT)
01	Turkey	7264	176,479
02	China	36,085	118,593
03	Uzbekistan	4293	76,865
04	Iran	6722	76,508
05	Morocco	4357	59,444
06	Azerbaijan	3764	32,290
07	Argentina	3322	28,482
08	Serbia	1893	12,318
09	Algeria	1860	11,693
10	Spain	1286	9331

capacity. The quince plant is naturally adapted to temperate climates, being unchallenged in cold temperatures and can easily endure mild winter periods. At the vegetative growth phase and fruiting stage, it indispensably requires high temperatures and higher luminosity (Duarte et al. 2014). This plant has a good lifespan of above 50 years, and it starts to provide a full-fledged fruit yield after 5–6 years of planting (Milic et al. 2010).

Regardless of its native region, the crop grows and performs well in varied countries of the world. Presently, quince is produced and commercially cultivated in more than 50 countries across the globe. The total globally harvested area is 82,943 hectares. In 2018, the total global production of quince was 688,660 metric tons (MT). The topmost producing countries were Turkey followed by China and Uzbekistan. The two countries Turkey and China in combination produced approximately 43% of the total world crop (295,072 MT). Iran, Morocco, Azerbaijan, Argentina, Serbia, Algeria, and Spain are the other countries among the top 10 in terms of production (Table 20.1).

About the global production scenario, it is pertinent to mention that once frequently grown in home fruit gardens, it has chiefly fallen out of favor in recent times and is a sort of neglected fruit. The economical production of the crop has declined significantly in many countries like the northeastern United States and Europe, though it still has some commercial significance as a fruit crop in Turkey and some countries of Asia. Apart from that, quince is very vulnerable to pathogenic diseases common to Rosaceae family members like entomosis, bacterial fire blight, bitter rot, black rot, and leaf spot which seriously affect the global production (Lopes et al. 2018).

Quince is not among the major cultivated fruit crops in India. Quince, being essentially a temperate fruit, grows in only a few regions of India. Jammu and Kashmir having temperate climatic conditions is the main quince-growing region, although a small production also takes place in Himachal Pradesh. These are only regions in India capable of growing the fruit since it requires recurrent cold periods with temperatures near to 7 °C for blossom with a temperate warm climate during another part of the year. In the Kashmir division, it is estimated that quince is cultivated for more than 470 hectares, mostly in the districts of Baramulla, Anantnag, Pulwama, Budgam, etc. These trees have a lot of genetic variability holding potential for the development or generation of refined varieties for enhanced fruit quality as well as quantity (Sharma and Sumbali 2000; Ahmad et al. 2008).

20.1.3 Botanical Description

Quince grows as a bushy small or medium-sized deciduous tree, with a height ranging from 5 to 8 m (16–26 feet) and a width or a canopy cover of 4–6 m (13–20 feet). Being a species of the Rosaceae family, it is closely related to apples and pears. The root is a tap root, deep feeder system with a sturdy stem having brownish bark. The leaves are intense green, simple with the entire margin having a length and width in the range of 6–11 cm and 4–6 cm, respectively. The leaves are oblong or ovate and tomentose on the lower side with an alternate arrangement. The pattern of venation in leaves is unicostate and reticulate. Buds are densely pubescent and small. The flowers sprout in spring or mid-April in the northern hemisphere after the leaves. They have a pinkish or white color with a size ranging from 4 to 5 cm across. They are solitary terminal in position on the leafy shoots, epigynous (inferior ovary), and pentamerous with 5 petals, 20 or more stamens, 5 styles, and 5 ovary chambers. Each ovary chamber contains many ovules. The immature fruit is green-colored with fine dense whitish hair (pubescence), which shed off toward maturity in late autumn. The mature fruit is a fragrant pyriform or globose pome (4–8 cm) with a weight of 100–280 g having a strong yellow color (Fig. 20.1). In warmer regions of the world, the fruit is softer and juicer, and in colder areas, it possesses hard stony highly fragrant unpalatable, acidic, astringent flesh (Milic et al. 2010). The ripe fruit emanates a distinctive odor with a short life due to the climacteric respiration property (Gunes 2008). However, storage at low temperatures (4 °C or below) impedes the ripening process and its effects. The fruit possesses many seeds almost up to 50. The seeds are brownish colored, compressed on both sides, and attached to white mucilage (Lopes et al. 2018). After ingestion, they nitriles in these seeds get hydrolyzed by the enzymatic or acidic action in the stomach, leading to a generation of hydrogen cyanide (HCN) which is a known volatile toxic gas and thus it is advisable not to consume them in large quantity (Ashraf et al. 2016).

20.2 Antioxidant Properties (Fruits, Juices, Seeds, Peels, Wastes, and Its Products)

Quince fruit when fully mature or ripe is yellow has a tough and hard flesh, possessing an astringent taste and distinctive fragrance. More than 70 genotypes and specific varieties are cultivated around the world as per an approximation (Wojdylo et al. 2013; Rasheed et al. 2018). Quince is considered to be a rich source of mineral elements such as potassium, phosphorous, magnesium, calcium, iron copper, zinc, etc. It also contains some organic acids like ascorbic acid, malic acid,

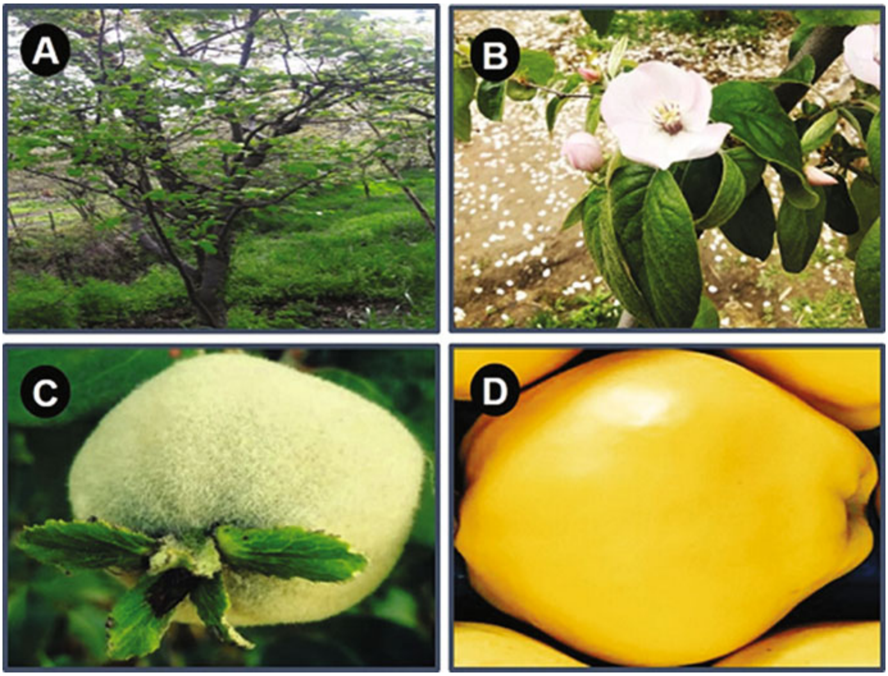

Fig. 20.1 Quince (Cydonia oblonga Mill.) (**a**) A quince tree growing in Jammu & Kashmir (India) (**b**) A branch with leaves and opened flowers. (**c**) Green immature fruit-bearing whitish hairs (**d**) Mature ripe fruit

and citric acid common in fruits. The fruit also has remarkable nutritional characters since it contains fiber, starch, pectin, proteins, vitamins, tannins, amino acids, and polyphenols (Lopes et al. 2018).

The antioxidant nature of quince fruits is predominantly owed to the occurrence of compounds like flavonoids and phenolic acids. The antioxidants present in fruits scavenge the free radicals which may produce the detrimental effects of certain degenerative and related human ailments like cancer, diabetes, and cardiovascular complications. Most of the antioxidant activity is achieved by the conversion of free radicals into stable molecular entities and thus breakage of the chain. The minerals present in fruits also help in free radical quenching since they are cofactors of several antioxidant enzymes (Anwar et al. 2018).

Quince produced in many countries is not edible and is nonpalatable as such because of its stiffness, acidic nature, and astringency. It is, however, used for the preparation of other eatable or drinkable products like jams, wine, and drinks and also in liquor making, juice, and puree. Besides, it is also used for the preparation of caramels, carbonated syrups, marmalades, and also for extraction of aromatic compounds. The nutritive value or composition of the fruit is subject to variation by climatic factors like rainfall, temperature, relative humidity, and light intensity (Rasheed et al. 2018).

In certain countries, like Argentina, the whole fruit after crushing is heated and the solid contents are passed through various sieves. A quince jam is made from the pulp by mixing with some additives and sugars. The solid material which is wasted or considered superfluous consists of skin fragments, seeds, and some portion of mesocarp (Baroni et al. 2018). The maximum amount of polyphenol molecules in the peel as well as seeds of the fruit necessitates the characterization of their antioxidant property (Silva et al. 2004).

The various beneficial components of quince fruit because of their antioxidant nature have other therapeutic benefits like anti-inflammatory, antihypertensive, antiatherogenic, and vasodilator effects. A literature survey has been conducted on the probable effects of quince in alleviating the complications of cardiovascular disease due to its prophylactic and therapeutic effects. The possible effects of these antioxidant constituents as defensive mediators in cardiovascular diseases is by their following abilities:

a) To chelate transition metal ions and the inhibition action of xanthine oxidase enzyme
b) Myocardial ischemic tolerance improvement to reperfusion injury
c) The influence of flavonoid components which causes mitigation of low-density lipoprotein (LDL) oxidation
d) Antiatherogenic influences in the blood vessels
e) Significantly influencing the bioavailability of nitric oxide and diminution of endothelial dysfunction
f) Decline in the discharge of mast cell mediator and lessening of the subsequent inflammation (Vaez et al. 2014).

Flavonoid components also have anti-inflammatory and antiplatelet accumulation via inhibition of appropriate enzymes and signaling transduction pathways. This results eventually in lower oxidant generation and improved reinstatement of blood in the ischemic region (Akhlaghi and Bandy 2009; Khademi et al. 2013). Quince fruit as well as the products are of pharmacological interest as they are cost-effective and naturally found sources of antioxidant compounds that exhibit principal antioxidative properties, which in turn are important for the alleviation of the pathology of several other diseases.

For the evaluation of antioxidant activity various components of quince fruit (pulp, peel, and seed) and jams, a phenolic fraction and an organic acid fraction were prepared for each sample and free radical scavenging ability or antiradical analysis was done by 1,1′-diphenyl-2-picrylhydrazyl (DPPH) assay. During the analysis of the phenolic fractions, it was found that the seed extract exhibited maximum antioxidant action with an IC_{50} of 0.1 mg mL^{-1}. The antioxidant activity was lesser in the peel extract with an IC_{50} value of 0.4 mg $mL^{-}1$ finally the pulp (IC_{50} of 1.0 mg mL^{1}) The two jams had parallel free radical scavenging capacities evident from their IC_{50} values of 7.0 and 6.0 mg mL^{-1}. It was observed that in organic samples, peel extract had maximum antiradical scavenging activity lowest IC_{50} value of 6.9 mg mL^{-1}, followed by pulp and seed extracts activities exhibiting

IC_{50} values of 11.6 and 12.9 mg mL^{-1} respectively. Organic acid extracts were the weakest in free radical quenching ability in every sample indicating that the phenol fraction is responsible for the prospective antioxidant nature of quince fruit. The jam prepared from unpeeled quince exhibited a higher antioxidant activity with IC_{50} values of 16.3 mg mL^{-1} than the one prepared from peeled fruits having IC_{50} of 22.6 mg mL^{-1} (Silva et al. 2004).

Baroni et al. 2018 studied the variations in antioxidant nature for quince fruits and waste material after jam production at an industrial scale by 1,1′-diphenyl-2-picrylhydrazyl (DPPH) and ferric-reducing/antioxidant power (FRAP) assays. It was concluded that jam processing did not cause any diminution in polyphenol content or antioxidant capacity. On the other hand, it was observed that the waste samples investigated during this study reserved substantial amounts of polyphenols, even though their antioxidant capacity was lesser than the fruit pulp. Values for jam in DPPH assay were 1325 ± 156 μM Trolox/100 g fresh weight (fw) which was almost 60% of those in pulp, that is, 2166 ± 156 μM Trolox/g fresh weight (fw). It is quite expected because this high percentage of pulp is present in the final jam product. In quite a contrast, DPPH values for two waste materials samples were 1367 ± 43 and 1374 ± 8.3 μM Trolox/100 g fw respectively, signifying the potential of these waste products. The results obtained from FRAP assay showed a similar pattern to the DPPH assay. The fruit pulp samples provided values of 2433 ± 191 μM Trolox/100 g fw in the FRAP experiment. As expected, jam samples presented FRAP values of only 1349 ± 335 μM Trolox/100 g fw again explained based on 60% of pulp quantity in jams. It is pertinent, however, to mention that waste samples had somewhat lower values than those obtained in DPHH assay (1017 ± 138 and 923 ± 8.04 μM Trolox/100 g fw, respectively. This study suggests that jams are also equally advantageous as the intact fruits and can be consumed for health benefits. It also warrants the retrieval and recovery of the waste materials for use in products since they also exhibited a substantial antioxidant potential.

The free radical scavenging power of a Quince Aqueous Fermented Extract (QAFE) and lipophilic Quince Wax Extract (QWE) was studied. QAFE was found to be effectually scavenging DPPH free radicals possessing an ID_{50} value of 68.8 μg/mL. It also exhibited prominent lipid peroxidation and at a minor concentration prohibited the formation of thiobarbituric acid reactive species at with an ID_{50} value 73.7 μg/mL. In contrast, the generation of superoxide radicals was more effectively inhibited by lipophilic QWE in comparison to QAFE with an ID_{50} of 48.9 μg/mL (Pacifico et al. 2012).

20.3 Characterization of Chemical Compounds Responsible for Antioxidant Properties and the Pathways Involved in the Biological Activities

Quince fruits are a valuable source of health-boosting and -promoting phytochemicals, which can be ingested or consumed as food and nutraceutical. The different pharmacological properties of quince products are not only due to their polyphenols such as tannins, flavonols, and their derivatives as their constituents but also due to the presence of polyphenol association with polysaccharides fractions (Pirvu et al. 2018). Due to the generation of free radicals and ROS during the usual processes of metabolism, body cells and tissues are vulnerable to the damage caused by them (Bhat et al. 2017). Polyphenols like phenolic compounds and flavonoids can exhibit interaction with reactive oxygen species (ROS) as well as reactive nitrogen species (RNS), and thus can terminate the chain reactions perilous to the body cells (Hussain et al. 2016). There are a plethora of studies that clearly show that quince fruits, in particular, are rich in polyphenols, organic acids, and amino acids with documented beneficial effects on human health. The flavones and catechins present in the fruits are chiefly dominant and beneficial for shielding the body against reactive oxygen species (ROS). The plausible mechanism seems to be the inhibition of lipid peroxidation and subsequent cellular membrane damage followed by a series of deleterious events culminating in cell death. Free radicals also draw various inflammatory mediators which elevate the general inflammatory reactions and damage to cells (Nijveldt et al. 2001). Vitamin C (Ascorbic acid) present in the quince fruits has the well-recognized antioxidant capacity and is regarded as a quality mark for their postharvest shelf life (Rasheed et al. 2018). Many studies have also focused on gauging the correlations between different classes of molecules and the antioxidant capability of edible parts of quince. An attempt was done to determine the antioxidant activity of methanolic extracts of various parts of quince fruit like peel, seed, and pulp as well as the jam. Each extract was further fractionated into a phenolic-rich and organic acid–rich fraction. The highly antioxidant phenolic subfraction of each part was analyzed by high-performance liquid chromatography (HPLC) with diode array detection (DAD). The chemical profiling of quince pulp and peeled jam extracts indicated that it contained six major phenolic compounds: quercetin, rutin, 3,5-dicaffeoylquinic, 3-O-caffeoylquinic, 4-O-caffeoylquinic, and 5-O-caffeoylquinic. Quince peel and unpeeled jam extracts were found to contain 13 phenolic compounds. Apart from the mentioned six compounds present in pulp and peeled jam extracts, they were also found to contain kaempferol 3-glucoside, kaempferol 3-rutinoside, etc. For the analysis of organic acids in the extracts, another technique HPLC-coupled ultraviolet (UV) detector was used. The extracts provided a similar profile which was comprised of seven recognized organic acids such as quinic, shikimic, oxalic, citric, ascorbic, fumaric acid, and malic acid. The inhibition of free radicals by extracts from all the fruit parts as well as jams were found to exhibit a strong correlation with caffeoylquinic acids and other phenolic compounds (Silva et al. 2004). A recent study by Sut et al. (2019) for evaluation of the presence as well as quantification study of secondary metabolites in peel and pulp was performed and compared to few varieties of apple by utilizing liquid chromatography-mass spectroscopy (LC-MS) coupled with diode array detection (DAD). The fruit was found to contain substantial quantities of derivatives of shikimic and quinic acid along with flavonoids and procyanidins. Apart from these, it was also found to contain certain other derivatives like kaempferol 3-O-rhamnoside, quercetin 3, 7-diglucoside, 4-caffeoylshikimic acid, 4-caffeoylquinic acid, and kaempferol 7-O glucoside. However, the most abundant compound in the pulp of fruit was determined to be 3-O-caffeoylquinic acid. The peel demonstrated the presence of high content of phenolic compounds. The DPHH free radical scavenging activity was very evident owing to the presence of a significant quantity of phenolics.

Another study focused on the changes due to jam processing of quince fruit at industrial scale on the content of phenolic compounds and their connection with the antioxidant ability. Waste materials from industrial processing procedures were also investigated for this purpose. By involving the analysis by HPLC–DAD–QTOF technique, at least 12 phenolics as well as 1 organic acid were recognized and quantified based on their retention times, mass fragmentation pattern data, and UV-Vis spectral data. The process of jam formation did not significantly alter the polyphenolic content. 5-p-coumaroylquinic acid was found to be a chief antioxidant constituent molecule (Baroni et al. 2018). Boosted regression tree (BRT) modeling was used to determine the correlation results in vis-à-vis FRAP and DPPH and the overall results were in agreement with the previously available literature (Silva et al. 2004; Wojdylo et al. 2013). In total, quinic acid (organic acid) and four hydroxycinnamic acids were identified during the sample analysis. The antioxidant activity could be attributed to flavonols present in a mixture of aglycone and glycosylated quercetin and kaempferol. Quercetin-3-O-rutinoside common flavonol was identified in the highest concentration. Flavonols mostly detected were chiefly catechins and procyanidins with (−) epicatechin representing the most significant one in almost all the samples. Waste samples were principally characterized by flavanols, and these samples had the highest concentrations of polyphenols (Baroni et al. 2018). It is pertinent to that in some contemporary studies for antibacterial (*Escherichia coli, Pseudomonas aeruginosa*, *Salmonella* etc.) activity of samples from quince fruit using the different hyphenated mass spectroscopic techniques, a majority of polyphenols for were distinguished, identified, and characterized taking cues from the unique fragmentation pattern in the ionization mode tandem MS spectra (Fattouch et al. 2007; Karar et al. 2013).

Phytochemical profiling analysis of 24 samples quince liquors obtained after macerating quinces from three varieties (ALM3, Vranja, and ZM2) peeled as well as unpeeled at two specific ethanol quince ratios. In total, 18 polyphenol compounds were identified by LC-PDA-QTOF/MS technique followed by subsequent quantification by UPLC–PDA and UPLC–FL. Flavanols were found to the utmost plentiful group in the samples followed by hydroxycinnamates. Some of the major compounds found were neochlorogenic acid, chlorogenic acid, (+)-catechin, procyanidin B2, quercetin 3-O-galactoside, glucosides of kaempferol and quercetin, etc. The high antioxidant activity of ZM2 fruit liquor in DPPH, FRAP, and ABTS assays was connected with the presence of a higher concentration of hydroxycinnamic acids (69.7 mg/100 mL) and flavonols (50.1 mg/100 mL) suggesting the prospective potential of the fruit alcoholic beverages (Carbonell-Barrachina et al. 2015).

Polar extracts of quince fruit (peel, pulp, and seeds), as well as leaves and flowers vegetative, were found to be potent against the growth and proliferation of human colon and kidney cancer cells. The well-known polyphenols in the peel and pulp of quince fruit extract synergistically inhibited the proliferation of human adenocarcinoma cells LS174 cells by promoting the apoptotic signaling pathway. The major compounds which were determined by the (HPLC–DAD) coupled online to a mass spectrometer (MS) were quercetin, rutin, hyperin, isoquercetin, chlorogenic acid, kaempferol, kaempferol 3-O-glucoside, kaempferol 3-O-rutinoside etc. These compounds could also explain the reported anti-inflammatory properties of these extracts in LPS-stimulated human THP-1-derived macrophages (Riahi-Chebbi et al. 2016; Ashraf et al. 2016). LC-MS analysis of an extract showed neochlorogenic acid as a major phenolic which reduced the degranulation of basophils and substantially declined the generation of interleukins IL-8 and tumor necrosis factor (TNF-α) from mast cells (Huber et al. 2012). The polyphenol compounds present in quince due to their hypoglycemic activity may also be the reason for the prevention and mitigation of the diabetic complications (Mirmohammadlu et al. 2015; Tang et al. 2016). The antioxidant and anti-inflammatory activity of polyphenols like chlorogenic acid and flavonoids such as quercetin, rutin, and kaempferol, etc. in quince fruit of also explains the reparation the colon damage due to IBD. The presence of copious amounts of pectin in these fruits shields from colon damage occurrence in colitis by supporting colonal cell growth and proliferation (Minaiyan et al. 2012; Ashraf et al. 2016). The cardioprotective potential of phenolics particularly 5-O-caffeoyl quinic acid and flavonoids, quercetin, and kaempferol 3-O-glucoside (Astragalin) and kaempferol 3-O-rutinoside in quince leaves emerges because of their ability to capture and quench ROS (Vaez et al. 2014; Pirvu et al. 2018). Extracts from fruits and leaves abundant in caffeoylquinic acid derivatives in addition to quercetin and kaempferol glycosides have been shown to have the lipid-lowering capability and alleviation of progressive atherosclerosis diseases (Khademi et al. 2013; Ashraf et al. 2016). Antiallergic and skin-healing effects of quince products can be attributed to the antioxidant nature of polyphenols, but also their collaboration with the mucilage fractions (Shinomiya et al. 2009; Pirvu et al. 2018).

The carotenoid pigments which are present and concentrated in the epidermal cells of the quince fruit also have a potent antioxidant activity such as β-carotene, lycopene, β-cryptoxanthin, lutein, and zeaxanthin. Also, some carotenoid derivatives were detected by mass spectrometric techniques like nuclear magnetic resonance (NMR) and gas chromatography (GC) coupled with mass analyzer. These derivatives were found to exhibit free radical scavenging and antiproliferative activity (Alesiani et al. 2010; Lopes et al. 2018).

20.4 Health Benefits and Medicinal Uses

Plants have the tremendous prospects to supply chemical compounds of varied nature and secondary metabolites that substantially exercise important biological functions and amend different pathological circumstances in the human beings (Sajid et al. 2015; Gul et al. 2017). The quince fruit has extensive nutritional features at par with or more than many fruits consumed by people all over the world. Apart from having a large quantity of water in the fruit pulp (76.50–81.20%), it is also a rich source of many beneficial components like organic acids (citric acid, ascorbic acid, malic acid) and minerals (magnesium, sodium, phosphorus, iron, calcium, copper, zinc, and potassium). The other dietary components which are present in the pulp include starch (7.30%), fiber (1.10–2.60%), proteins (0.47–0.71 g/100 g), total sugars (10.90 g/100 g), and lipids (0.21–2.40 g/100 g). Besides, it is a nice nutraceutical source of antioxidants like vitamin C (ascorbic acid) (15.32 g/100 g) and other health-boosting phytochemical compounds such as phenolic acids (Lopes et al. 2018). In addition to being an energy source (48–57 kcal), the fruit can be consumed as a beneficial source of health-boosting vitamins like A, B complex (pantothenic acid, pyridoxine, riboflavin, thiamin, niacin), E, and K (Duarte et al. 2014). Some processed food products are also prepared from quince fruit such as jam, jelly, tutti-fruity, and murabba (sweet fruit preserve) (Ahmad et al. 2008). In several European countries and parts of Latin America, a paste or a jelly-like fragrant sweet confection (membrillo) made from quince is consumed with cheese after cutting into pieces. Quince is also consumed with wine and cooked for sweet dishes and savory in many parts of the world (Ghazarian 2009; Hummer et al. 2011). It is mentioned in a few utterances (Ahadees) of the Holy Prophet (PBUH) about its health benefits as *Tib e Nabvi* (Prophetic medicine). He said "Eat the Al Safarjal – (the Arabic word for quince) since it can cure the heart diseases and provide relief from the burden of chest." In one more instance, he narrated that eating quince creates breath as pleasant and gives strength to the heart (Rasheed et al. 2018). Almost all parts of *Cydonia oblonga* such as leaves, buds, fruits, seeds, and bark, etc. have medicinal properties and health benefits. The leaves have been used in some cultures for cardiovascular and dermal problems. The decoctions and infusions from leaves are being consumed from ancient times in various traditional medicine systems because of their antipyretic, sedative, antitussive and antidiarrheal benefits. The seeds are also considered to have certain pharmacological benefits against certain conditions such as cough, dysentery, bronchitis, constipation, and sore throat. The fruit is regarded as very useful against diabetes, urinary problems, respiratory ailments, and ulcers (Sabir et al. 2015, Ashraf et al. 2016). There is empirical evidence based on animal models of quince parts being advantageous for their antispasmodic, antihypertensive, anti-ulcerative, hepatoprotective, and kidney protective roles (Fig. 20.2) (Fazeenah and Quamri 2016). A concise account of the scientific research and hence validation of some of the significant medicinal properties of quince is given as follows.

20.4.1 Antiallergic Properties

The antiallergic property of quince fruit extract obtained by hot water has been examined in vivo as well as in vitro. A significant reduction of the release of β-hexosaminidase was obtained post-application of 50, 100, and 200 μg/mL of extract to cell culture. Because of this, after 3 weeks, atopic dermatitis marks developed in the mice's treated group on the face, head, nose, neck, and dorsal

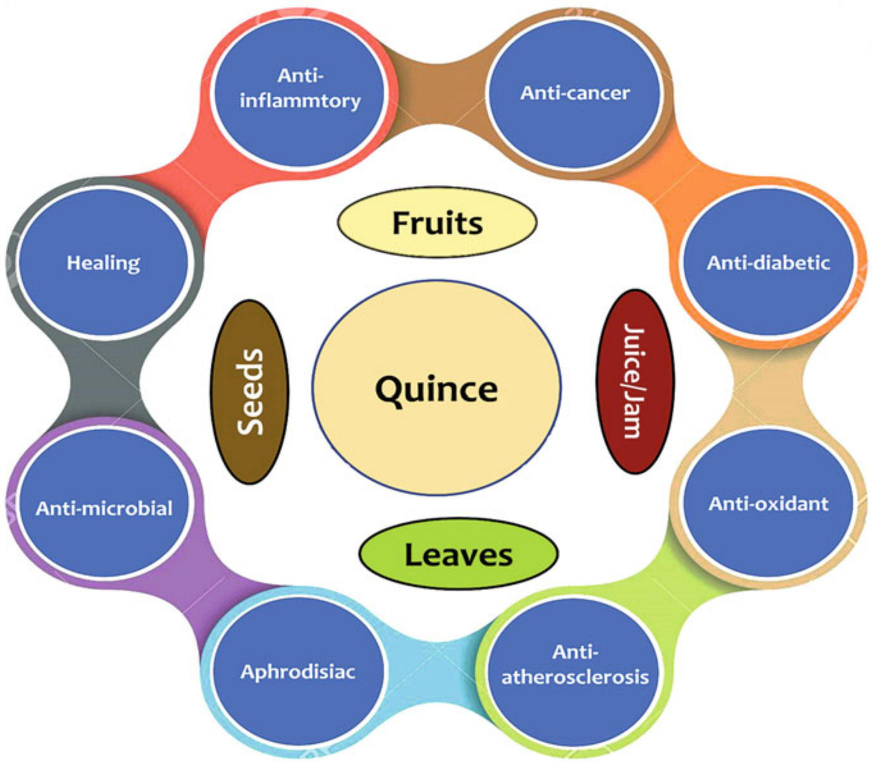

Fig. 20.2 Some remarkable health benefits/medicinal properties of various parts of quince

skin of mice were significantly low as compared to control group. A 5% hot water extract treatment to animals reduced immunoglobulin E (IgE) levels to 994 ± 205 ng/mL as compared to 1635 ± 289 ng/mL present in control group. (Silva et al. 2008; Shinomiya et al. 2009; Sabir et al. 2015).

20.4.2 Antidiabetic Properties

A study on the antidiabetic effect of quince leaves hydroethanolic extract on normal and streptozotocin-induced diabetic rats was carried out. Not any remarkable effect on normal rats after consumption of 2 g/kg glucose was observed. However, it is pertinent to mention that at a period of 0–3 h, a considerable decline in the blood glucose levels of diabetic rats was noted. The advantageous effect in terms of decrease in glucose level by the extract (250 or 500 mg/kg dried extract) was at par with the standard antidiabetic drug (tolbutamide, 100 mg/kg) in rats (Aslan et al. 2010). In one more study, oral administration of the aqueous fruit extracts once in a day in doses of 80,160, and 240 mg/kg body weight for 6 weeks to male streptozotocin-induced diabetic Sprague–Dawley rats efficaciously caused a reduction in cholesterol level, serum triglycerides, low-density lipoprotein cholesterol accompanied with an increase in high-density lipoprotein cholesterol. A remarkable reduction in two important renal dysfunction serum markers – urea and creatinine – was also attained. In addition to that, serum biomarkers of liver dysfunction such as alkaline phosphatase (ALP), alanine transaminase (ALT), and aspartate transaminase (AST) showed a considerable fall in the extract-treated diabetic rats. Therefore, quince fruit can be consumed as it is beneficial to ward off complications linked with diabetes (Mirmohammadlu et al. 2015).

20.4.3 Anticancer Properties

The methanolic extracts of quince leaf and fruit (seed, peel, and pulp) were evaluated for antiproliferative activities against kidney and colon cancer cell lines, and there was a clear distinction in their cancer cell inhibition potential. Although renal adenocarcinoma cells were seldom affected by the leaf extract, a concentration-dependent growth-inhibitory pattern in human colon cancer cells with an IC_{50} of 239.7 ± 43.2 μg/mL was observed. In total contrast, the fruit and seed extracts displayed no prominent effect on colon cancer cell growth. Nevertheless, a strong antiproliferative proficiency of the extract for the highest concentration used (500 μg/mL) against renal cancer cells was perceived (Carvalho et al. 2010). The molecules isolated from the peel extract were examined for their growth inhibitory prospects against murine melanoma B16-F1 cancer cells. Subsequently, among the compounds, it was shown that ursolic acid was the most effective one which inhibited the growth of the cells lines in a concentration-wise pattern demonstrating an IC_{50} value of 10.2 μM (Alesiani et al. 2010). In one more such study, the aqueous fermented and lipophilic wax extracts of quince were similarly shown to possess the cancer cell inhibitory potential toward human HepG2, A549, and HeLa cell lines. Overall, the aqueous fermented extracts were more potent in cell inhibition as compared to lipophilic wax extracts ((Pacifico et al. 2012). Thus, from these studies, it is implied that various organs including the fruit of quince may be beneficial as a cancer chemo-preventive and/or chemotherapeutic agent.

20.4.4 Anti-inflammatory Property

The efficacy of polyphenol fruit peel extract against lipopolysaccharide (LPS)-induced in the human THP-1 cell line inflammatory model was studied. It was observed that the polyphenol extract significantly inhibited the discharge of LPS-induced inflammatory mediators like interleukin (IL-8) and cytokines (TNF-α), which confirm and validate that the polyphenol peel extract of quince is a potent inducer of anti-inflammatory effect (Essafi-Benkhadir et al. 2012). In another study, quince leaf extract was shown to successfully mitigate symptoms of arachidonic acid–elicited ear edema and carrageenan-induced paw edema in rats.

The extract exercised its inflammatory activity via inhibition of nitric oxide, lipid peroxidation, IL-6, and TNF-α intensity causing a decline in edema (Ahmad and Bastawy 2014).

20.4.5 Antimicrobial Activity

The ethanolic extracts obtained from quince seeds were checked for their antibacterial activity against gram-positive and gram-negative bacteria by agar well diffusion technique. It was demonstrated that extracts had inhibited potential greater toward the growth of gram-positive bacteria as compared to gram-negative bacteria. *Staphylococcus aureus* was more vulnerable to the seed extract while *Moraxella* and *Escherichia coli* showed a substantial resistance (Al-khazraji 2013). In another study, water, ethanolic and acetone extracts of quince fruit, as well as seeds were investigated for checking their inhibition potency against several pathogenic bacteria like *Escherichia coli*, *Enterobacter aerogenes*, *Klebsiella pneumonia*, and *Staphylococcus aureus*. The results showed that the ethanolic extracts of quince seed extracts were most efficient against bacterial pathogens as compared to aqueous and acetone extracts (Alizadeh et al. 2013). Another study showed that ethanolic extract of leaves and silver nanoparticles of quince exhibit synergism for antifungal activity effect against *Aspergillus niger* which causes infections (Hamid et al. 2014). Quince juice (10%) inhibited a usual pathogenic strain of *Helicobacter pylori* bacteria in the agar diffusion method. A synergistic outcome of quince juice with certain others like bilberry, black choke, green tea, sweet flag rhizome, etc. was also realized in this experiment (Babarikina et al. 2011). A phenolic extract obtained from quince at a concentration of 0.5 mg/mL was found to be significantly potent and efficient in inactivation and inhibition of the influenza virus in the hemagglutination assay (Hamauzu et al. 2005).

20.4.6 Aphrodisiac Activity

The aphrodisiac activity of hydroalcoholic quince fruit extract was examined on Wistar rats after oral administration. The result showed that the mating performance and mounting frequency in rats was significantly raised after the extract administration. The extract also caused some behavioral alterations in male Wistar animals compared to control (nontreated ones), which made them captivating and attractive toward females. This study is in line with the claimed role of quince as an effective libido rejuvenator in Unani sand Tib e Nabvi systems of medicine (Aslam and Sial 2014).

20.4.7 Anti-atherosclerotic Activity

A comparative analytical study of the influence of 50 mg/kg quince leaf extract and standard medication atorvastatin (0.5 mg/kg) was conducted for the progression of atherosclerosis in the rabbit model. The results showed that the quince leaf entirely caused a reduction in the lipid profile content in plasma comparable to atorvastatin. There was also a significant decline in the liver enzymes, that is, aspartate transaminase, alanine transaminase, and alkaline phosphatase of the leaf extract–treated rabbits. These overall results of the lipid-lowering ability of quince leaf indicate that quince can be a prospective source of natural products for atherosclerosis management and treatment (Khademi et al. 2013).

20.4.8 Antioxidant Activity

It is now considered as fact in the scientific circles that the pathology of a number different ailments such neurodegenerative, cardiovascular, cancer, etc. are closely linked with the generation and subsequent reactions of free radicals (Pham-Huy et al. 2008). From the various studies carried out from time to time, it has been observed that quince fruit, leaves, seeds, and other products are rich in various polyphenolic compounds and derivatives which account for its antioxidant activity (Silva et al. 2004; Baroni et al. 2018; Oliveira et al. 2007).

20.4.9 Healing Potential

Seeds of quince have been known to possess the wound healing capability since traditional times. For scientific validation of the same, the healing influence of seed mucilage from the seeds on skin scratches caused due to T-2 toxin was investigated. The rabbits were subsequently divided for this experiment into five classes. Groups 1 and 2 were treated with poison as positive control and with Eucerin as negative control, respectively. The remaining groups were provided with 5%, 10%, and 15% seed mucilage treatment. Consequently, an 83 mg/mL methanolic solution of T-2 toxin was applied on the skin of these rabbit groups two times at an interval of 24 h. The results were observed on the eighth day and it was seen that the rabbits in the groups provided 10% and 15% quince seed mucilage had realized complete healing of the skin damage. In total contrast to this, the rabbits present in Groups 1 and 2 as well as that provided with only 5% mucilage had inflammation and erythema. It was inferred that due to the seed mucilage treatment, the skin had fully recovered from damage and becomes normal with hair growth. The plausible mechanism or effects which account for the wound healing capability of the quince seed mucilage is by (1) acting as an obstruction between T-2 toxin and skin as well with decreasing evaporation water, (2) preventing disturbed protein synthesis caused by T-2 toxin, (3) exercising itself as an antioxidant as well as a growth factor, (4) the promotion of the process of blood circulation and expediting the assembly of granulated tissue, and (5) the enhancement of the fibroblasts function and eliciting the collagen development, etc. (Hemmati et al. 2012). A polysaccharide glucuronoxylan obtainable from seeds of the quince plant is utilized for the making of dermal films for the healing of wounds, however, it needs safety profile evaluation (Ashraf et al. 2016).

20.5 Conclusion

It is a fact that that choice of dietary foods is directly and closely connected with significant health benefits. That is why the intake of fruits and vegetables regularly does play a pivotal role to improve the quality of health life. All over the world, plants with medicinal or pharmacological benefits behave an alternative or complementary medicine in healthcare purposes for treating various disorders and an upsurge in demand for them grows day by day. Quince (*Cydonia oblonga* Mill.) is one of the members of commercially significant apples and pear family (Rosaceae). The quince fruit is an excellent as well as an economically feasible natural source of beneficial phytochemicals and its health benefits have been considerably known to the folklore people in different civilizations. Apart from this, the other parts quince plant, such as leaves and seeds, are also used because of their pharmacological benefits. The pharmacological tests both in vitro as well as in vivo have given proof for its claims of benefits in the traditional system of medicine. However, it has been neglected in recent years and the production has declined in several regions of the world. Thus, there is a need to further evaluate its medicinal potential and make people aware of its health benefits, so that not only quince is conserved, but its production increases all over the world.

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Kinnow

21

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Abstract

Kinnow, a citrus fruit, belongs to the *Rutaceae* family. The fruit has bright attractive color with juicy and thirst-quenching properties. Peel, pomace, and seeds are the three components of the fruit produced after the juice extraction process. All these three components contain different bioactive components which are having beneficial properties. Peel is a rich source of polyphenols, carotenoids, and essential oils while seed contains high amount of lemonoids. The phytochemicals show antioxidant properties and can be used as additive in place of artificial antioxidants. The chapter gives the insight about the kinnow fruit, its structure; different bio-actives present in each part of the fruit, and health-related benefits.

Keywords

Kinnow · Peel · Pomace · Seed · Juice · Antioxidant

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21.1 Introduction

India has observed a tremendous upsurge in horticulture production over the past few years. During 2016–2017, the production of horticulture crops was about 295.2 million tons from an area of 24.9 million hectares (Anon 2017). In 2016, the world production of all citrus fruits was 124 million tons. In 2018, the citrus production in India was 12.55 million metric tons. In Punjab, citrus varieties are being grown over 52,836 ha, with an annual production 1,049,977 tons (Rattanpal et al. 2017). Punjab has an area of 51,000 ha under cultivation of kinnow fruit, with an average yield of about 11,000 MT in 2016–2017 (Anon 2017). It occupies about 61.9% of total fruit area in Punjab, and ranks first in fruit production in India (Anon 2017; Arora et al. 2018) Kinnow mandarin (*Citrus reticulate L.*) is a hybrid of King and Willow Leaf and belongs to the citrus family (Arora et al. 2018). In India, J. C. Bakhshi introduced this variety in 1954 at the Punjab Agricultural University, Regional Fruit Research Station, Abohar (Aulakh et al. 2008).

Kinnow fruits are juicy, and the juice extracted at an appropriate stage of maturity has a characteristic pleasing aroma, refreshing flavor, and thirst-quenching properties. Morphologically, the fruit has been divided into two main sections, the peel and pulp. The external colored portion is called "flavedo," which consists of pigments in the form of chromoplast and oil glands. The internal white part is called albedo. Both the albedo and flavedo (peel) contain a higher concentration of phytochemicals and pectin than other parts of the fruits. The edible portion (pulp) consists of segments and the ovarian locule, which is filled with juice sacs. The main composition (in terms of percentage) of kinnow are 85–90% water, 6–9% sugars, and less than 2% for pectin, acids, essential oils, minerals, fat, protein, and fiber (Izquierdo and Sendra 2003).

Kinnow fruits are endowed with diverse phytochemicals which are important for both disease prevention and health promotion. They are the plant nutrients that have a particular biological activity which establish one of the most numerous and broadly distributed substances in the plant kingdom. The therapeutic and dietetic properties of almost all citrus fruits are related due to their phytochemical contents (Okwu 2008). Citrus plants accumulate and synthesize these phytochemicals including low molecular phenolics in their cells (Okwi and Emenike 2006). The composition of these bioactive components in fruits and vegetables is highly variable according to the genotype, plant tissues, (Henríquez et al. 2010; Lutz et al. 2015) and is generally affected by the pedoclimatic situations, agricultural practices, postharvest storage, and processing (Tomás-Barberá and Espín 2001; Baiano 2014).

Citrus peels are the richest sources of bioactive phenolic compounds, especially bioflavonoids, with comparatively higher polyphenol content compared to the pulp (Safdar et al. 2017). In citrus fruits, about three-fourth of the vitamin C is present in the peel, pulp, and seed that goes waste (Nagy 1980; Mann and Aggarwal 2013). There is a growing acceptance that amino acids, phenols, pectin, essential oils, flavonoids, carotenoids, and ascorbic acid existing in citrus species provide beneficial effects in the deterrence of degenerative diseases (Wang et al. 2014).

Many researchers have explored the phenolic potential of kinnow fruit parts for cosmetics, functional foods, and medical use. Some flavonoids like hesperidin and neohesperidin have been transformed into their dihydrochalcones, considered as natural sweeteners (Ortuno et al. 1995). Naringin is utilized to flavor beverages, sweets, and bakery goods because it has a distinguishing bitter taste (Giannuzzo et al. 2003). Furthermore, anthocyanins are utilized as coloring agents (E163) in confectioneries, dairy foods, and sweets or to compensate for the fading fruit in the food industry. Currently, extraction of flavonoids from kinnow peel has also attracted considerable scientific interest, due to its number of health implications.

Kinnow fruit requires sharp contrast warm and cool temperature along with a freezing temperature during winter for high-quality fruits and good cropping. This fruit has thrived well in Haryana, Punjab, foothills of Himachal Pradesh, and some parts of Rajasthan. Punjab cultivates kinnow on approximately 48,000 hectares (ha) area that comprises 4000 ha in Bathinda district, 5600 ha in Muktsar, 6300 ha in Hoshiarpur, and 27,000 ha in Abohar–Fazilka belt (Rattanpal et al. 2017). The characteristic feature which makes kinnow different from other citrus varieties are the kinnow peel contains a number of oil glands and comes off easily as it is not tightly bounded with the skin of the fruit, it has a high juice content and easily separable sections, and a single kinnow fruit when consumed provides good vitamin C content to the human body. The pulp of the fruit can be utilized for jams, sauces, and delicious desserts. This chapter gives insight regarding kinnow structure and bioactive compounds in various parts of the fruit and their health implications.

21.2 Structure Characteristics of Kinnow

Kinnow fruit is surrounded with peel in order to guard the pulp of the fruit containing juice sacs and seeds. The peel outside is made up of cuticle, which covers the epidermal layer, that is, the flavedo, and has a number of oil glands, containing essential oil providing aroma to the fruit. The flavedo portion also contains chromatophores, which are the minute color-providing bodies, green in undeveloped fruit and progressively turning orange or yellow in the developed fruit or as the fruit matures. Parenchymatous cells are present in the white spongy portion of the fruit which is termed as albedo and lies under flavedo. The cells of albedo are distributed uneven with lightly organized intercellular spaces. It contains a water-soluble fiber called pectin which can be recuperated as citrus pectin. Segments or locules are present in the inner part after flavedo, which is segregated by a thin membrane of epidermal tissue and contains various juice sacs in the shape of the spindle along with seeds. In each segment, the juice vesicles are attached with a segmented wall that is in contact with peel by fine threads. The juice sacs centrally situated comprises oil droplets that are embedded in cellular tissues. The segment membranes and core are together termed the “rag” of the extracted juice (Petracek 1996). Kinnow fruit shape is oblate without a neck portion. The fruit is round in shape at the basal end portion and flat at the stem attachment point along with truncated distal end. The fruit is big in size with an average of 68 mm in diameter and55.2 mm in height, with the flat, orangish rind and slightly visible, depressed oil glands. The peel is relatively thin and slightly adherent at maturity, 2.5 mm in thickness approximately. The inner side of the fruit has smooth flesh texture with 10–11 segments that are juicy, 145 g in weight, and averaging 49% juice (Rattanpal et al. 2017).

21.3 Bioactive Compounds with Health Benefits in Different Parts of Kinnow Fruit Their By-products

The kinnow fruit and its juice are considered a valuable part of a healthy diet. The wide range of bioactive compounds and nutrients in the citrus promotes a healthy lifestyle and provides protection against various chronic diseases (Baghurst 2003). Free radicals are produced by the oxidation reaction that is capable of attacking the healthy cells, which results in loss of their structure and function. These damaged cells are the major contributor to aging and degenerative diseases like cancer, cataracts, cardiovascular diseases, brain dysfunction, and declined immune system in human beings (Mishra et al. 2014). These formed free radicals can be controlled by compounds known as antioxidants that neutralize the free radicals or their actions (Devasagayam et al. 2004). The ability of the kinnow chemical components acts as an antioxidant due to their ability to form a delocalized unpaired electron and stabilizing the produced phenoxyl-radical after reaction with lipid radicals (Babbar et al. 2005). These antioxidants are divided into two classes based on their sources, that is, natural and synthetic. To prevent the lipid peroxidation and oxidation of food components, the synthetic antioxidants are used by the food industry. Butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and tert-butylhydroquinone (TBHQ) are some commonly utilized synthetic antioxidants. From the last few years, the safety and toxicity issues regarding synthetic antioxidants have been raised as these materials may cause the liver swelling while influencing the liver enzyme activities and carcinogenicity. The natural antioxidant as an alternative for synthetic antioxidants may have health implication benefits besides greater solubility in both oil and water (Babbar et al. 2005) Natural antioxidant occurs in all parts of the plant including carotenoids, vitamins, phenols, flavonoids, etc. (Yadav et al. 2016), which too are present in the kinnow fruit. Kinnow fruit is a rich source of bioactive compounds that have several health-promoting properties contributing to free radicals scavenging effect, anti-inflammatory, antimicrobial, antimutagenic, and neuroprotective, etc. The development of natural antioxidants and free radical scavengers from the plant-based material, rich in polyphenolic compounds are considerable interest nowadays (Singh et al. 2016; Mathur et al. 2011). The citrus fruits contain various physiologically active compounds including ascorbic acid, citric acid, and minerals along with flavonoids like hesperidin, naringin, neohesperidin, naringenin, rutin, nairutin and tangeretin (Tanizawa et al. 1992; Kawaii et al. 1999). Basically the citrus peel holds a number of biologically active components such as flavonoids and phenolic acid (Bocco et al. 1998; Manthey and Grohmann 2001; Giannuzzo et al. 2003). These flavonoids possess antioxidant activity and have the ability to capture an electron and block free radicals. The kinnow flavonoids form a tautomeric dislocation, which prevents the chain reaction of free radicals (Okwu 2008). Kinnow flavonoids similarly exert neuroprotective effects as it is involved in the modulation of neuronal activities and mental health including brain plasticity, depression, mood, etc. Hesperidin flavonoid can protect the neurons against various neurodegenerative diseases (Castro-Vazquez et al. 2016). The major phytonutrients present in kinnow are alkaloids (0.38 mg/100 g), flavonoids (0.26 mg/100 g), tannins (0.02 mg/100 g), phenolics (0.03 mg/100 g), and saponins (0.03 mg/100 g) (Okwu 2008).

21.3.1 Kinnow Peel

Post juice extraction from kinnow fruit, major quantities of agro-industrial waste, such as peel, seed, pomace, and pulp are produced, in which peel is maximum in concentration. Due to the lack of proper infrastructure to handle this huge quantum of biomass, the residue does not find any commercial utilization (Babbar et al. 2011). Their disposal in open spaces creates the problems of environmental pollution (Makris et al. 2007). Around 30–40% of kinnow peel is obtained as major by-product during processing (Rafiq et al. 2018; Yaqoob et al. 2020a, b). It was observed that the kinnow peels have a higher concentration of vitamin C, carotenoids, and phenolics components with essential oils in comparison to the pulp and contain excellent antioxidant potential. The composition of the kinnow peel oils include total terpenes (99.13%) along with pinene, sabinene, myrcene, and limonene; as well as total aromas (0.54%) including linalool, decanal, and others (0.33%) (Danielski et al. 2008). The bioactive compounds from the kinnow peel is recovered by valorization that found potential diversified utilization in cosmetic, pharmacy, and food industry (Kaur 2016). Different methods are used for the extraction of these polyphenolic compounds from the kinnow peel. Conventional extraction techniques, that is, maceration and soxhlet along with nonconventional like ultrasound-assisted extraction, microwave extraction, and supercritical fluid extraction are some common methods to extract these bioactive components (Ross et al. 2009; Belova et al. 2009; Da Porto et al. 2009). As studied by Singanusong et al. (2014), the kinnow peel contains naringin, hesperidin, total flavonoid (TFC), and total phenolic contents (TPC) of 514.65 mg 100 g^{-1}; 528.77 mg 100 g^{-1}; 2146.40 mg quercetin eq 100 g^{-1}; and 2456.71 mg gallic acid eq 100 g^{-1}, respectively. It has been observed that out of methanol, ethanol, and acetone solvent extraction of phenolics from the kinnow peel, acetone extracted highest phenolic compounds, as acetone and kinnow flavonoids having a similar structure containing C=O functional groups. These natural antioxidants have a pivotal role in human health due to their antioxidant enzyme cofactor, chelation of pro-oxidant metal ion in body, as well as free radical scavenging activity. As kinnow processing waste contains valuable nutrients and biomass, it can be converted into valuable by-product such as natural antioxidant for the prevention of oxidation in meat processing industry (Safdar et al. 2017). The kinnow rind powder is used as a safer alternative of synthetic antioxidants (Da Porto et al. 2009; Devatkal et al. 2010). Losses of many phytochemicals observed during drying of kinnow peel are as follows. Rafiq et al. (2018) reported freeze drying following by vacuum drying to preserve the thermo-sensitive phytochemical and color of kinnow peel. A small fraction of kinnow peel residue is being utilized as beverage base, marmalades, and candied peel (Senevirathne et al. 2009). The major bioactive phenolic compound of kinnow peel is flavanoids mainly flavones, isoflavones, flavonones, flavanols, and anthocyanidins that acts as important antioxidants due to their high redox potential, ability to act as hydrogen donor, and singlet oxygen quencher (Senevirathne et al. 2009). The kinnow peel flavones and polymethoxyflavones represent the capability for the destruction of cell membrane permeability of bacteria and simultaneously inhibition of protein synthesis. This ability makes flavones an effective antimicrobial agent against bacteria and fungus (Kaur 2016). The major cause of food deterioration is the oxidation that takes place in food results in loss of nutritional components along with the destruction of flavor (Babbar et al. 2011). As reported by Tumbas et al. (2010), the presence of hesperidin and narirutin polyphenolics and inhibition of peroxidation of kinnow mandarin peel extract indicate that kinnow peel can be used as a safe additive with antioxidant activity and substitute of the synthetic antioxidant in food processing industry with prolonging the shelf life of food products containing fats and oil (Tumbas et al. 2010). The hesperidin reduces cholesterol and has anti-inflammatory effects (Okwu 2008). As the kinnow peel is rich in bioactive compounds that represent the natural antioxidant activity, it can be used for the value addition of many food products. Mann and Aggarwal (2013) incorporated frozen kinnow peel into ice cream at the level of 2%, 3%, and 5%. The results showed that the ascorbic acid and flavonoids content of ice cream increased with the increased incorporation of frozen kinnow peel.

Kinnow peel is also rich in bioactive compounds such as limonin (60–80 ppm) that exhibit tremendous health benefits including anticancer, anti-inflammatory, antiviral properties, and antioxidant activity (Dua and Kocher 2017; Manners 2007). Nowadays, the research frontier is more focused on the study of thousand phytochemicals rather than on the deficiency diseases of classic vitamins. There is a broad consensus that the phytochemicals can provide versatile health benefits while diminishing the cancer risks. Limonin is the most abundant limonoid aglycone found in the citrus tissue and seeds. As reported by Miller et al. (2004), the work was conducted on the cancer chemo-preventive activity of citrus limonoids. It was observed that the limonin could inhibit the development of carcinogen-induced cancer in animal models for stomach, lungs, and skin cancer (Miller et al. 2004). Limonoids possess the antitumor activity by stimulating the enzyme glutathione S-transferase (Okwu 2008). The naringin, known for the bitterness of citrus fruit, is present in the kinnow peel and commercially important due to its antioxidant and antimutagenic properties. The diabetes-induced neuropathy reduction, protective action against cognitive oxidative damage, and dysfunctions were observed for naringin present in the peel (Giannuzzo et al. 2003; Kandhare et al. 2012).

21.3.2 Kinnow Pulp

When the kinnow fruits are processed for the juice and other products, the remaining residue is known as pomace, which is utilized for the production of pectin and molasses. It has been found that the kinnow pomace possesses a number of biologically active components, that is, antioxidants, phenolics, and flavonoids but the content of these compounds is less than peel (Yaqoob et al. 2020a, b). Thus, the kinnow pomace can be used as a raw material for the value addition of many food products (Hayat et al. 2010). An alternative for the synthetic antioxidants for food and pharmaceuticals is the growing interest nowadays. The customer's safety concern supports the idea of natural antioxidants because the synthetic molecules promote the negative health effects (Dilas et al. 2009). The intake of food containing natural antioxidant helps in the prevention of disease caused by oxidative stress (Dilas et al. 2009). The imbalance between the pro-oxidant and antioxidant agents is known as oxidative stress and caused either by an excess of pro-oxidant agent or deficiency of antioxidants and might be both. Different forms of the basic phenolic acid content present in kinnow pomace are given in Table 21.1. Kinnow pomace contains maximum phenolic acids in bounded form. It has been found that the concentration of phenolic compounds could be prejudiced by the geographic origin, cultivar, time of harvesting, storage, and processing conditions (Mallavadhani et al. 2006).

After the juice extraction the by-product (pomace) is rich in glycosylated flavones, flavones, flavonoids, and phenolic acids (Tables 21.1 and 21.2). As per reported by Hayat et al. (2010), the kinnow pomace has 18.4% and 30% 2,2-diphenyl-1-picrylhydrazyl (DPPH) and hydroxyl radical scavenging assay,

Table 21.1 Phenolic acid content and FCs (μg/g DW) of kinnow pomace

Phenolic acid content			
Forms	**Gallic**	***p*-Hydroxybenzoic**	**Vanillic**
Free	114	89.4	292
Ester-bound	106	120	325
Glycoside-bound	32.2	80.4	46.5
Total	252	290	664
Forms	***p*-Coumaric**	**Ferulic**	**SPCg**
Free	234	399	1128
Ester-bound	570	1092	2214
Glycoside-bound	18.4	65.0	2.43
Total	823	1556	3585
Flavonoid content			
Catechin	15.6	**Free**	14.80
Hesperidin	4541	**Bound**	5.01
Total	4556	**Total**	19.81

SPCg sum of individual phenolic acids content, *FCs* Flavanol, flavanone and flavonol
Source: Hayat et al. (2010), Gaganjot (2013)

Table 21.2 Phenolic compounds and antioxidant activities of kinnow pomace

Phenolic compounds extracted in water- and acetone-treated kinnow pomace			Antioxidant activity of bound and free phenolic compounds in kinnow pomace		
Phenols (mg/g)	Water treated	Acetone treated	Antioxidant activities	Free phenolic	Bound phenolic
Hesperidin	0.546	27.697	Hydroxyl radical scavenging activity (%)	63.17	53.65
Naringen	0.042	8.102	Reducing power (abs.)	0.265	0.191
Naringenin	0.065	0.085	DPPH radical scavenging activity (%)	57.06	42.40
Limonin	0.045	17.14	Fe2+ chelation assay (%)	42.90	59.83
Gisha et al. (2018)			Trolox equivalent antioxidant capacity (mg TE/g DW)	54.37	117.48

respectively. The correlation between antioxidant activity and total phenolics of fruits and vegetables has been widely studied and has been found to exist linear (Minatel et al. 2017).

A different class of flavonoids and their derivatives, that is, flavones, flavonols, flavanols, flavanones, isoflavones, and anthocyanidins represents the largest group of phenolics compound in the kinnow pulp. Singh et al. (2016) reported that the kinnow pulp contains 354.9 and 261.3 TPC (mg GAE/100 g) and TFC (mg QE/100 g) respectively, while the antioxidant activity (mM TE/g) is reported in terms of DPPH and ABTS as 2.9–3 and 3.3–3.5, respectively. From various classes of phenolics, the kinnow pulp contains caffeic acid (16.8 mg/100 g), ferulic acid (12.3 mg/100 g), sinapic acid (14.4 mg/100 g), and kaempferol acid (14.2 mg/100 g).

21.3.3 Kinnow Seeds

During the processing of kinnow fruit into various food products, a considerable quantity of kinnow seed found as a waste. These kinnow seeds create environmental and disposal problems (Matthaus and Ozcan 2012). As the kinnow residue (seed) is easily available, inexpensive, and composed of bioactive compounds, it can be used as a source of antioxidants. It was identified that the kinnow seeds are an important source of essential oil including palmitic (15.77%), stearic (2.62%), oleic (23.53), linoleic (45.92%), arachidic (0.36%), linolenic (4.92%), behenic (0.29%), and arachidonic (0.10%) (Al Juhaimi et al. 2018) and found its application in nutritional, pharmaceutical, and cosmetic industries. These seeds are also rich in phytochemicals, carotenoids, and tocopherols. The major phenolic compound found in kinnow seed were 1,2-dihydroxybenzene, kaempferol, catechin, and isorhamnetin (Table 21.3) (Al Juhaimin et al. 2018). As per mentioned by Al Juhaimi et al. (2018), the kinnow seeds contain 28.01% antioxidant activity and 158.16 mg/100 gm total phenolic content, while Babbar et al. (2011) reported the antioxidant activity and TPC of kinnow seed were 20.50 (mg TE/g-DW) and 3.68 (mg GAE/

Table 21.3 Phenolic compounds of kinnow seed (mg/100 g)

Gallic acid	5.113
3,4-Dihydroxybenzoic acid	4.412
(+)-Catechin	9.341
1.2-Dihydroxybenzene	13.171
Syringic acid	3.795
Caffeic acid	3.406
Rutin trihydrate	3.199
p-Coumaric acid	0.272
Trans-ferulic acid	6.150
Apigenin 7 glucoside	4.160
Resveratrol	0.128
Quercetin	3.816
Trans-cinnamic acid	0.296
Naringenin	3.398
Kaempferol	10.780
Isorhamnetin	7.592

Source: Al Juhaimi et al. (2018)

g-DW) respectively. A major class of compounds called limonoids have also been found in maximum concentration as compared to other fruit parts (Yaqoob et al. 2020a, b).

21.3.4 Kinnow Juice

The kinnow fruit is famous in all parts of India, mainly in Punjab and Rajasthan, because of its distinctive flavor and the presence of important phytochemical compounds that are associated with different health benefits. Due to the increased production of kinnow in India, the demand for the processed products of kinnow, mainly juice, increased in recent years due to variations in the taste preferences, dietary traditions, and the way of present-day consumers (Bhardwaj and Pandey 2011). Also, the perishable nature and abundant production during peak seasons require processing to evade postharvest losses. The natural kinnow juice beverage has more medicinal, nutritional, and calorific value than the synthetic beverages. The presence of abundant vitamin C, carotenoids, and phenolic compounds plays an vital role in the total antioxidant activity of kinnow juice with a fair amount of vitamin A, calcium, phosphorous, and iron (Peterson et al. 2006; Dhaka et al. 2016). In the previous report (Al Juhaimi et al. 2018), the TPC, DPPH, and ascorbic acid activity of kinnow juice was 91.8 mg/100 ml, 59.19%, and 52–53 mg/100 ml reported respectively. The ascorbic acid also plays an essential role than phenolic compounds in formulating antioxidant power of kinnow juice (Sun et al. 2002; Ghafoor and Al-Juhaimi 2011). The kinnow juice contains a significant number of vitamins including ascorbic acid (31.66 mg/100 g), B1 (0.12 mg/100 g), B2 (0.01 mg/100 g) and niacin (0.43 mg/100 g). The vitamin C content of kinnow juice acts as an antioxidant in the skin by scavenging and quenching the free radicals generated by UV radiations stabilization (Okwu 2008).

21.3.5 Kinnow By-products

Nowadays, the trend is more toward the food products with natural antioxidants and free from synthetic additives (El-Samahy et al. 2009). The whole kinnow, pulp, juice, and its by-products could be used as a natural antioxidant in the food products. Mann and Aggarwal (2013) developed phytochemical-enriched ice cream by fortification of kinnow peel. The ascorbic acid and the total flavonoids provided antioxidant activity. The results depicted by the author showed that the ice cream with incorporated blanched kinnow peel at the rate of 1%, 3%, and 5% represented 3.7 and 63.3, 5.4 and 78.3, and 6 and 81.1 of ascorbic acid (mg/100 g) and naringin (μg/g) content, respectively. While in terms of blanched kinnow peel–incorporated ice cream contains 2.9 and 46.6, 4.5 and 68.1, and 5.1 and 74.4 of ascorbic acid (mg/100 g) and naringin (μg/g) content, respectively. As previously reported by Sidhu et al. (2013), the osmotically dried kinnow peel candy and peel powder contains approximately 30 and 40, 170 and 165, and 38 and 30 of ascorbic acid (mg/100 g), naringin (μg/g), and limonin (μg/g) content, respectively. According to Aggarwal and Michel (2016), the whole kinnow with peel was converted into candy using sucrose and fructose. The kinnow candy contains 11.2–11.4 mg/100 g of ascorbic acid and 410–412 ppm of limonin content. Yaqoob et al. (2020a, b) prepared muffins from kinnow peel and its phytochemicals and found that the fortified muffins contained higher phytochemical and antioxidant activity as compared to the artificial antioxidants.

21.4 Health Benefits of Kinnow

Kinnow fruit has shown to possess numerous potential health benefits. As per the scientific finding the consumption of 100 ml fruit juice per day has the potential to reduce chronic diseases mainly cancer, inflammation, and cardiovascular diseases (Bhardwaj et al. 2014). The antioxidants and polyphenolic compounds in the fruit juices play an essential role in the interaction of metabolic activities in the human body as a therapeutic agent. Ascorbic acid of the kinnow juice acts as a powerful antioxidant in the body to protect it from oxidative stress and increase immunity for many diseases. The common kinnow components and their health benefits are given in Table 21.4.

Table 21.4 Health benefits of different bioactive compounds

Bioactive compounds	Health benefits	References
Ascorbic acid	Antioxidant boosts immune system, protection against scurvy, heart disease, cataracts, infection, and cancer. Maintain the skin collagen and elevating the nonheme iron absorption to almost double that prevents the iron-deficiency anemia, stimulate the absorption of iron and zinc from other foods. Serves as cofactor in several important hydroxylation reaction, that is, biosynthesis of catecholamines, L-carnitine, cholesterol, amino acids, and peptide hormones. Acts as potent free radical scavenger in plasma, and protects the cell against oxidative damage by reactive oxygen species (ROS). Cytoprotective function of vitamin C includes prevention of DNA mutation by oxidation, protection of lipids against pro-oxidative damage. In the presence of free transition metal like copper or iron, it acts as pro-oxidant and cancer cell killer. Reduce the incidences of malignancies in humans. Anti-inflammatory, prevent apoptosis, improve neurotransmission, and reduce risk of cataract formation	Grosso et al. (2013) and Devaki and Raveendran (2017)
Carotenoids (β-carotene, lutein, cryptoxanthin)	Beta carotene as precursor of vitamin A, protection against infection, cancer, cardiovascular diseases, and slow the build-up of plaque in arteries. Acts against reactive oxygen species, inactivate free radicals, and modulate gene expression. Plays a protective role in condition of diabetes, cardiovascular diseases, inflammation, apoptosis, hepatic steatosis, fibrosis, oxidative stress, etc. Lutein reported anti-inflammatory properties, improvement of eye and cardiovascular health; prevent age-related macular diseases, and decrease risk of cancer. Cryptoxanthin associated with reducing the risk of cervical cancer, anti-obesity effect, antioxidant activities, anti-inflammatory, and anti-cancer activity	Elvira-Torales et al. (2019), Eldahshan and Singab (2013), Buscemi et al. (2018) and Jiao et al. (2019)
Folic acid	Prevents neural tube defect in children; stabilizes genetic material and protective action against cancer; essential for the prevention of premature births, spina bifida, and maintaining a low level of homocysteine (marker of inflammation) that has been associated with heart diseases, stroke, and heart failure; helps in the production of DNA, RNA, and mature red blood cells that prevent the onset of anemia	Baghurst (2003), Castro-Vazquez et al. (2016) and Economos and Clay (1999)

(continued)

Table 21.4 (continued)

Bioactive compounds	Health benefits	References
Terpenes (monoterpenes, triterpenes; limonoids including limonene, perillyl alcohol)	Limonene is used to dissolve gallstones, and has anticancer properties; helps in complete regression of mammary and pancreatic tumor, and inhibits the development of breast cancer in humans as well as reduces the cholesterol level. Cancer prevention phenomenon of limonoids reduces the DNA damage; helps to repair DNA followed by reduction in mutations leading to cancer and also stimulate the detoxifying enzyme system. They act as diuretic and aids in relieving gastrointestinal spasms. They possess antimicrobial activity, and are helpful in fighting with microorganisms resistant to antibiotics, that is, fungi and yeast. Also has anti-inflammatory, antitumorigenic, and neuroprotective properties	Kandi et al. (2015) and Cho et al. (2017)
Flavonoids (flavanones, flavones, flavanols, and anthocyanin, including 60 individual flavonoids)	Protection against cancer, fungal infection, inflammatory diseases, allergies, and heart strokes; exert neuroprotective effects as they are involved in the modulation activities and mental health. Antioxidant, antitumor, anti-inflammatory, antiplatelet, antiallergic, antiviral, anticarcinogenic, antiproliferative, antiallergic, antidiabetic properties, antineoplastic activities, and hepato- and gastroprotective	Tanwar and Modgil (2012), Yao et al. (2004), Baghurst (2003), Castro-Vazquez et al. (2016) and Economos and Clay (1999)
Phenols, hydroxycinnamic acid, flavonoids, catechin, and flavones	Polyphenols have wide range of health benefits including antioxidant, antiviral, antiallergic, anti-inflammatory, and anticarcinogenic properties. Antioxidant property scavenges the naturally occurring free radicals before they can damage the macromolecules directly or indirectly involved in either lipid proliferation or cell proliferation. Kinnow polyphenols block the formation of carcinogenic nitrosamines. Protective effect of polyphenols against acute and chronic diseases including obesity, diabetes type 2, and neurodegenerative diseases. Quercetins possess anti-inflammatory properties, prevent cardiovascular diseases, fights influenza A virus, and have antiulcer, antiallergy, and anti-proliferative effects.	Cory et al. (2018) and Rasouli et al. (2017)
Phytosterols, limonoids	Anti-inflammatory and antitumor activity, inhibit blood clotting, protection against chronic diseases including cardiovascular diseases, cancer, degenerative eyes, and damages caused by aging. Phytochemicals present in the kinnow juice inhibit chronic diseases like diabetes, osteoporosis, cardiovascular disease, arthritis, brain disease, and cancers	Baghurst (2003), Castro-Vazquez et al. (2016) and Economos and Clay (1999)

Fibers (soluble and insoluble polysaccharides, pectin etc.)	May reduce the risk of certain cancers like colorectal cancer; prevent heart diseases, strokes, hypertensions, diabetes, blood cholesterol level, obesity, certain gastrointestinal diseases including gastroesophageal reflux disease, duodenal ulcer, diverticulitis, hemorrhoids; improve the gut microflora, and decrease the transit time of food in the gut	Anderson et al. (2009) and Li and Komarek (2017)
Minerals (potassium)	Potassium with accurate ratio of sodium may help in the regulation of high blood pressure; provide protection against age-related bone loss, helpful in reductions of kidney stone, and reduce cardiovascular disease mortality	Weaver (2013) and He and MacGregor (2008)
Bioflavonoids (hesperidin)	Antioxidant, anti-inflammatory, anticarcinogenic, antimicrobial properties, cell aggregation inhibition, antiallergic effect, UV-protecting activity, radioprotection; significantly reduce the reactive oxygen species (ROS) generation in cells and restore the mitochondrial enzyme activity	Kuntic et al. (2014)

21.5 Conclusion

Kinnow fruit, a hybrid of *Citrus nobilis* and *Citrus deliciosa*, has been grown extensively in northern India. It is widely known for its high juice content and is mostly processed into various beverages. The fruit parts like peel, pomace, juice, and seeds are important sources of bioactive compounds possessing antioxidant activity and other health benefits. Excluding juice, other parts of the fruit are usually thrown away which pose a serious environmental problem. Being rich source of these potential bioactive compounds, it can be concluded that these parts can also be utilized in the fortification of food products.

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Pear

22

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Abstract

Pear (*Pyrus communis* L) is full grown in temperate and subtropical conditions since its more extensive adoptability. Sparkling pear fruit is eaten worldwide and additionally typically found in processed products like beverages and protected natural products. Pear fruit is rich in macronutrients as well as in micronutrients. It is a rich source of dietary fiber and vitamin C. Distinctive types of phenolic compounds too are displayed in peels, blossoms, seeds, bark, and leaves. The phenolic contents are higher within the pear skins than in its pulp. Pear has good wound restoration property. Pear is a skin brightening specialist. The boron substance in pear makes a difference in the body to hold calcium, which progressively impedes osteoporosis. Pear is wealthy source of fructose and dietary fiber. The purgative properties of pear are explained by the presence of fructose and fibre substance. Pear and pear products have shown prominent results in pain relieving, antineoplastic, antidepressant, antibiotic antimicrobic and resistant booster. Utilization of pear natural product, containing wealthy phytoconstituents, amid a slim down is aiming to be accommodating in ensuring the body from hurtful oxygen radicals. Moreover, it is too recommended that natural products ought to be devoured with their peels, since it is thought that the oxidation reducing action

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that they require is successful in ensuring the wellbeing and anticipating illnesses. This topic presents a comprehensive study of the phytochemical constitution, antioxidant properties, dietary regard, prosperity benefits, and therapeutic properties of pear.

Keywords

Pear-*Pyrus communis* · Phytoconstituents · Ascorbic acid · Phenolic compounds · Antioxidants · Oxygen radicals

22.1 Introduction

22.1.1 History

Pear is considered to be one of the foremost imperative temperate natural product crops (developed in all temperate regions of the world) having a place to family Rosaceae and subtribe *Pyrinae* (containing about 1000 species). The subtribe *Pyrinae* is distinguished by certain synapomorphic characters (pome fruit, basic chromosome number $x = 17$, and gametophytic apomixes). Its pleasant taste makes it widely accepted throughout the world. The shape of pear has been a source of inspiration for designers and architects. Jean-Baptiste, the botanist of gardens of Versailles Palace, wrote the following lines about his passion for pears "it must be admitted that among all natural products in this put nature does not sow anything so wonderful nor so able as this pear. It is pear that produces the most noteworthy honor on tables." Its origin has been traced to the region encompassed between Southeast Europe and the Black Caspian Sea (Caucasus region). Homer in his written records of 1000 BC referred to pear as "Gift of The Gods." Theophrastus (371–281 BC) stated that grafting and cuttings were common practices of pear culture in ancient Greece. The migration of famous Indo-Europe tribes is considered to be a reason of the spread of pear into European and Northern India.

The relocation of celebrated Indo-Europe tribes is considered to be a reason of the spread of pear into European and Northern India. It is detailed that there were more than 100 assortments of pear by the conclusion of the Sung Line of China (1279 AD). Cordus (1515–1544) portrayed diverse pear assortments in Deutschland having all the characteristic thing characters had by appear day cultivars, with the special case of creamy surface.

It isn't certified when the pear was appeared into Britain, however, slanted a number of times as of late the Roman victory. The English need to be expert pear breeders inside the 1800s, outlined in 1826 catalog of the Recognized Society of London posting 622 cultivars. The preeminent essential cultivar by and by made inside the earth, "Williams Bon Chretien" ("Bartlett"), was recognized approximately 1796. The pear overhaul happened in Europe from two species: *P. communis* and *P. nivalis*. The elemental, European Common pear, is totally devastated and has in its gene pool an impact of other species, such as *P. eleagrifolia*, *P. spinosa*, *P. nivalis*, and *P. syriaca*. The diminutive, utilized to create wine, has been of unbelievable importance in Britain and France for over 400 years. Most cultivars released in Europe were made through open fertilization and common things were chosen concurring to their delicate quality and buttery viewpoint (Heywood and Zohary 1997).

22.1.2 Production

Based on the information from the Nourishment and Agribusiness Organization Corporate Factual and Database, in terms of generation of pear, China is currently the leading country in the world with an annual production of 16.5 million tons. China is followed by Argentina with an annual production of 930,340 tons. Italy is the third-largest maker with an yearly generation of 772,577 tons taken after by the Joined together States of America with an yearly generation of 677,891 tons. The entire generation of pears within the world for the year 2017 was assessed to be 24,168,309 metric tons stamping an increment of 2.1%. China roughly accounts for 67%, that is, two-thirds of worldwide generation in this manner proceeds to be the biggest maker so distant. The annual production of pear in India was 322.24 thousand tonnes in 2015–2016.

22.1.3 Botanical Description

The Asian and European continents have an age-old history of pear cultivation dating back to about 5000 years. There are five main species of pear that are cultivated out of all the reported and known species and interspecific hybrids. These are as follows:

1. *P. communis*
2. *P. pyrifolia*
3. *P.* × *bretschneideri*
4. *P.* × *ussuriences*
5. *P.* × *sinkiagensis*

Natural products, that is, fruits of European pear are characterized by stretched structure and full-bodied structure whereas Asian pears are circular in shape and have a sandy surface. The class *Pyrus* is known to contain 75–80 species and interspecific crossbreed species. Rendering refinement among diverse species is troublesome due to a few hybridizations. *Pyrus* may be a class of bushes and deciduous trees creating straightforward clears out orchestrated on the other hand. Some species have glossy green leaves while some have densely silvery hairy. Pear tree is a spur or lateral bearer; flowers are white in color and borne in corymbs. Its flower composition has five sepals, five petals, free styles with a five locular ovary, and has numerous stamens. Pear is classified as a pseudo-fruit consisting of a greatly dilated calyx tube which encloses the true fruit. It has a core consisting of five cartilaginous carpels. Different *Pyrus* species are differentiated on the basis of morphological characters like the appearance of leaves, calyx, and fruit. There is a wide extent of diversity in pear cultivars over the world in terms of taste, texture, and shape.

Different *Pyrus* species are differentiated on the basis of morphological characters like the appearance of leaves, calyx, and fruit. There's a different degree of contrasts in pear cultivars over the world in terms of taste, surface, and shape. A number of pear species are made commercially (Bell et al. 1996).

Pyrus species had been categorized into three organizations: little fruit bearing species with two carpels, expansive fruit bearing species with five carpels, and their go breeds with three to four carpels. There are nearly five crucial little fruit species (too referred to as Asian pear species), essentially dispersed in China, Japan, and Korea, which are applied for fancy functions or as rootstocks. In China, blooming and accumulating run from March to April and August to September, personally. Maximum *P. communis* cultivars are harvested in overdue August to early September, whereas the complete gather season stages from July to November. Stepped forward capability improvements empower the accessibility of pears in markets all year round. Early cultivars are extra worthwhile in China, so there's a slant for breeding prior developing cultivars in Asian countries.

One of the foremost characteristics of Asian pears is the firm, sugary, and delightful destructive squash. The squash is characterized by having "stone cells," which are sclerenchyma cells that contrast from fiber since they are exceptionally elongated. They too offer a sandy surface to the fruit. The sizes change from adjusted as apples, these being the foremost developed, until pears to the best and foot prolonged bulbous pears, comparative to the European pears. The characteristic items are uncommonly delicate to physical hurt, both at gather and within the classification as capacity and promoting (Layne and Quamme 1975).

22.2 Antioxidant Properties

22.2.1 Fruits

Different varieties of pears possess diverse dietary composition, diverse antioxidant properties, and hence show distinctive taste and smell. Table 22.1 shows different phytoconstituents in different parts of pear. Lee et al. (2011) detailed that phytoconstituents and their subsidiaries are catholic in pear natural products. Pinelo et al. (2004) concluded that the free radicals are frequently deactivated by phytoconstituents with oxidation reducing action, like vitamin C, vitamin E, carotenoids, and anthocyanins. Li et al. (2014) compared the total phenolics, total triterpenes and total flavonoids between skin and pulp of 10 different pear varieties and observed a significant difference among the different pear cultivars. In addition, it was found that phytoconstituents found in pear skin were around 6 to 20 times more than pulp. Silva et al. (2010) analyzed the antioxidative potential of pear natural products amid long-term capacity and observed that the cancer prevention agents and oxidation reducing agents can be kept up to 8 months.

Table 22.1 Phytochemicals in pear (*Pyrus communis* L.)

Pear parts	Phytochemicals present in *P. communis*	References
Leaves	Arbutin, isoquercitrin, sorbitol, ursolic acid, kaempferol 3-*O*-β-D (6″-*O*-α-L-rhamnopyranosyl)-glucopyranoside, quercetin 3-*O*-β-D-(6″-*O*-α-L-rhamnopyranosyl)-glucopyranoside	Gudej and Rychilnsk (1999)
Bark	Friedelin, epifriedelanol, and β-sitosterol	Rychilnska and Gudej (2013)
Root bark	Phloridzin	Nortje and Koeppen (1967)
Fruit	Arbutin, isoquercitrin, sorbitol, ursolic acid, kaempferol 3-*O*-β-D (6″-*O*-α-L-rhamnopyranosyl)-glucopyranoside, quercetin 3-*O*-β-D-(6″-*O*-α-L-rhamnopyranosyl)-glucopyranoside, vitamin A, vitamin C, vitamin E, vitamin B12, vitamin B3, vitamin B5	Razavi et al. (2009)
Flowers	Chlorogenic acid fatty acid	Razavi et al. (2009)
Stem bark	Triterpenoids	Li et al. (2013)

22.2.2 Juices

Pear juice acts as a food nourishment with rich vitamin C content & potassium, and low calories than citrus and fruit juice (Xie et al. 2007). Rocha et al. (2013) detailed that pear juices appeared higher corrosive levels, more sharpness, and more antioxidant action than the apple juices, which were sugary and with more seriously color.

22.2.3 Seeds

Consistent with the research conducted by Hashemi et al. (2018), it was detailed that wild pear seed oil contains the most noteworthy sum of α-tocotrienol rise to 1.1 mg/100 g oil. Traces of other tocotrienols (β, γ, and δ) were present. Pear seeds in expansion to greasy acids and phytosterols contain different dietary and non-nutritional phytochemicals of tall restorative and mechanical utilization. Mushtaq et al. (2019) detailed that pear seeds' linoleic corrosive level was found to be higher as compared to other utilized eatable oils.

22.2.4 Peels

The wholesome and utilitarian nourishment esteem of natural products are frequently superior caught on by evaluating their cancer prevention agents and bioactive profile which progressively may depend upon the sort of natural products and their development conditions (Scalzo et al. 2005). Manzoor et al. (2013) detailed that pear skin has been shown to have a completely higher antioxidant movement and phenolic substance compared to the pulp and, hence, can be effectively utilized in pharmaceutical applications. Abaci et al. (2016) detailed that different pears developing inside the environmental conditions of Ardahan are wealthy in antioxidant movement. The exceptionally best sum of phenolic substances most elevated antioxidant action was watched inside the “Bal” variety of pears. There was a much better phenolic substances and antioxidant action inside the pear genotype skins than in their tissue. Kevers et al. (2011) analyzed the impact of varieties, collect time, capacity conditions, and peeling on the antioxidant capacity and phenolic and ascorbic corrosive substance of pears and finally concluded that peeling driven to diminish total phenolic and ascorbic corrosive substance more than 25%.

22.2.5 Wastes

Leaves, unused peels, pulp, seeds, and spoiled fruits constitute the fruit wastes. Lin et al. (2012) considered the oxidation reducing abilities, phenolic substance, and their relationship, for water and fat-soluble extricates of the buildups of pear natural products and natural product buildups having most grounded antioxidant properties were sorted as appeared in Table 22.1. The coordinate relationship between antioxidant power and add up to phenolic substance demonstrated that phenolics can be one among the foremost supporters to the antioxidant capacities of those natural product buildups.

22.2.6 Antioxidant Properties of Products Prepared from Pear

Pear is additionally utilized for the generation of handled nourishments like natural product wine. Reliable with inquire about the study conducted by Ruberto et al. (2007), the antioxidant movement of the natural products (fruits) and natural product jams was straightforwardly related with the substance of phytoconstituents, and these compounds can be debased by physical–chemical components related with nourishment handling. Devi et al. (2018) detailed that wild pear was found to be a legitimate source of vitamin C, phenols, and carotenoids, and may be effectively utilized for the planning of sort of great quality and nutritious items’ gainful cost. Wit and Smiechowska (2017) concluded that the oxidation reducing properties of perry wine and perry emulate drinks were lesser in comparison to other drinks coordinated from pear.

22.3 Characterization of Chemical Compound(s) Responsible for Antioxidant Properties and the Pathways Involved in the Biological Activities

The main cause of deterioration in food is the oxidative reactions. Such reactions are mainly responsible for the losses in nutritional, value, and degradation in taste, texture, and aroma. By the reaction of important functional molecules with the

Table 22.2 The main phenolic compounds vitamin C (mg/kg) present in pear

Pear	Phenolic compounds	Vitamin C
Peel	Chlorogenic acid, ascorbic acid, dehydroascorbic acid, flavonols and arbutin	116–228
Pulp	Dehydroascorbic acid	28–53
Flesh	Chlorogenic acid	

Source: Ferreira et al. (2002)

Table 22.3 Arbutin and chlorogenic acid content found in different pear plant parts

Plant organ	Arbutin (mg/g fresh weight)	Chlorogenic acid (mg/g fresh weight)
Floral bud	12.4	3.22
Leaf bud	11.9	2.26
Young fruit	9.92	3.72
Flower	8.29	5.32

Source: Cui et al. (2005)

products of biological compounds in the human body, the cell homeostasis can get disturbed and can become a cause of various diseases like heart failure, tumors, cataract, brain dysfunction (Maniak and Targoński 1996). The process of oxidation in the human body as well as in food products is inhibited or prevented with the help of antioxidants. The natural antioxidants occur in all edible products of plant and are thus considered to be a stable part of nutrition. Polyphenols are the most numerous group of antioxidants as they are found in fruits and vegetables. The existence of chlorogenic acid, arbutin, p-coumaroylmalic acid, catechin, epicatechin, proanthocyanidins, cyanidin 3-*O*-galactoside and some nonglycosylated flavones and flavonols in different parts of pear tree-like skins, flowers, fruits, etc. was earlier investigated by researchers. In a comparative study of ten cultivars of pear for evaluating the composition of total flavonoids, total triterpenes, and total phenolics between pulp and skin of the fruit, it was found that concentration of phenolics contents is much higher and it varies greatly in pear skin rather than the fruit pulp (Table 22.2). After the thioacidolysis of a Portuguese pear cultivar was conducted by Ferreira et al. (2002) (*Pyrus communis* L. var. S. Bartolomeu) the phenolic compounds in it were determined. In harvested fruits, the average composition of phenolic compounds was found to be 3.7 g/kg of fresh pulp at the stage of the commercial stage. The presence of phytochemicals like procyanidins, arbutin, catechins, and hydroxycinnamic acids was also determined.

In an analysis conducted by Cui et al. (2005) on the phenolic compounds in the oriental pears, two main components were identified in one of the major cultivars of *P. bretschnrideri.* The two compounds arbutin and chlorogenic acid were identified during development.

The arbutin and chlorogenic acid contents found in different plant organs are shown in Table 22.3.

Table 22.4 Concentration of phenolic compounds in pear

Phenolic compound	Content (mg per liter)
Chlorogenic acid	73.1–2.49
Epicatechin	11.9–81.3
p-Coumaric acid	0.0–3.0
Caffeic acid	2.4–11.4

Source: Tanrioven and Eksi (2005)

The concentration of arbutin and chlorogenic is found to be highest in young fruits during its development. The arbutin concentration present in the fruit peel is found to be 10–45 times greater than its concentration in the pulp and 3–5 times greater than in the core. On the other hand, the concentration of chlorogenic acid in the peel is found to be lesser than that in the core. Tanrioven and Eksi (2005) conducted a study on different phenolic compounds present in juice samples from seven different varieties of pear (Table 22.4).

Lignin has also been reported as an antioxidant in pear by Bunzel and Ralph (2006). Lignins are considered to be essential noncarbohydrate component of dietary fiber. They are related to fibers of wheat bran and cereals.

22.4 Health Benefits

According to a systematic review conducted by the Federation of American Societies for Experimental Biology on the consumption of pear and its health outcomes, it was found that there is a high concentration of fructose and dietary fiber in pear. The laxative properties associated with pear is explained by the fructose content present in it. The amount of phenolics provided by the consumption of per 100 g of pear ranges between 27 and 41 mg. Experimental studies done on the benefits of pear on human health suggest that pears provide protection against ulcers, lower the content of plasma lipids, and regulate alcohol metabolism. Most of the studies suggest that there is an important role of pear in maintain gut and bone health. A clinical study on smokers reveals that consumption of pear reduces the total cholesterol level and the total plasma antioxidant capacity (TAC) remains unchanged in them. Due to the concentration of vitamins (especially vitamins C and A) and minerals like electrolytes, phytochemicals, and antioxidants, pear holds a historical place in dietary guidance. Evidences suggest that the health benefits associated with pear are due to the interactions or synergy of bioactive compounds and other nutrients present in whole foods. Some unique health benefits have been revealed by some studies. Pear intake is linked with some protective properties. Pears add a good amount of potassium to the diet. Potassium and dietary fiber are considered to be nutrients of concern in the US diet. Antioxidants are concentrated in flavones particularly anthocyanin. Intake of pears is linked with reducing the incidences of type 2 diabetes and stroke. Pears in general provide positive health outcomes like improvement in gut health, which have been shown in intervention studies with pears.

Some of the most important health benefits of pear are summarized as follows.

22.4.1 Bone Health

The boron content in pear helps in retaining the calcium in the body and thus slows down osteoporosis. It also helps in the maintenance of body pH (Flaishman et al. 2004).

22.4.2 Immune Booster

Due to its cooling property, there is a mild antipyretic effect in pear juice. The antioxidant nutrients present in pears have an important role in building up of our immune system (Kaur and Arya 2012).

22.4.3 Cardiovascular Disease

Pear helps in curing cardiovascular disorders by preventing high blood pressure and stroke (Reiland and Slavin 2015).

22.4.4 Action on Urinary System

Leaf extract of pear acts as an uro-disinfectant and urinary infections are relieved with the help of compound arbutin present in pear (Gudej and Rychilnsk 1999).

22.4.5 Respiratory Diseases

The heat of the summer season often causes the problem of breathlessness with excessive phlegm. By drinking pear juice the inflammation of the vocal cord is reduced, throat is nourished, and thus helps in clearing the phlegm (Newman 2017).

22.4.6 Weight Loss

Pear helps in accelerating the process of weight loss by binding pectin (a type of fiber) to fatty substances present in the digestive tract and eliminates them (De Oliveira et al. 2008).

22.4.7 Constipation

Due to the presence of pectin in it, the pear is considered to be a gentle laxative. Regular intake of pear juice helps in regulating regular bowel movements. Pectin promotes the elimination of fatty substances by binding with them in the digestive tract. However, individuals already suffering from irregular bowel movements may suffer from stomach pain, gastric upset, and diarrhea upon consuming pear (Bae 2014).

22.4.8 Pregnancy

Neural tube defects in infants can be prevented by the consumption of pear as it contains a high amount of folate (Olsen et al. 2020).

22.4.9 Anticancer Activity

The risk of bladder, lungs, and esophageal cancer can be reduced by the consumption of pear on a regular basis. Urosolic acid present in pears inhibits the activity of aromatase and thus prevents cancer. DNA integrity is maintained by isoquercitrin present in pear fruits (Büchner 2009; Linseisen 2007; Freedman 2007).

22.4.10 Antimicrobial Activity

Extract of leaves and fresh fruit juice show antibacterial activity against *Staphylococcus* and *Escherichia coli* due to the presence of a bacteriostatic phytoconstituents arbutin. Its due to the further conversion of arbutin into hydroquinone which also possesses antibacterial activity. Hydroquinone plays an important role in boosting biochemical processes and acts as a defense mechanism against invasion of bacteria. Extracts of young shoots also contain hydroquinone and thus show antibacterial activity (Guven et al. 2006; Jin and Sato 2003).

22.4.11 Antioxidant Activity

Being a rich source of vitamin C, quercetin, and copper, pear protects cells from damage by free radicals. Reactive oxygen species are destroyed by different parts of the pear tree (Sharma et al. 2015).

22.4.12 Cholesterol Lowering Activity

The levels of LDL, triglycerides, and VLDL are lowered down by the consumption of pear thus reducing the risk of high cholesterol (Velmurugan and Bhargava 2013).

22.4.13 Wound Healing Effect

Pear is highly effective in speeding up the healing process of different types of wounds. There is an abundance of carotene, zeathene, and vitamin C in pear which stimulates the process of production of collagen—the structural unit of protein in the skin. Tannins present in pear help by constricting the wounds (Velmurugan and Anurag 2014).

22.4.14 Antidiabetic Activity

The high amount of fiber present in pear helps in the maintenance of low levels of glucose in diabetics. In addition to this, low levels of fructose and sucrose in pear can be well tolerated by such patients (You et al. 2017).

22.5 Conclusion

This chapter is based on different investigations and experiments conducted on the composition of phytoconstituents and their antioxidant activities in pear (*Pyrus* spp.) and its parts. It is inferred that pear is a fortune of minerals, phenolic compounds, and vitamins which make it a sound dietary supplement. Eating a pear before a significant drinking meeting can generally decrease your blood alcohol. Pear has different helpful properties, for instance, hypolipidemic, antioxidant, antibacterial, uro-disinfectant, sedative, anti-inflammatory, anticancer, wound healing, antibacterial, analgesic, spasmolytic, hepatoprotective, antidiabetic, and antipyretic property. It is also advised that pear should be consumed along with its peel, as its antioxidant activity is quite effective in the maintenance of health and prevention of diseases.

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Peach

23

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Abstract

Peach (*Prunus persica*) belongs to Rosaceae family and believed to have originated in China 8000 years back, although it was thought that peach is native to Persia. Now it is grown in many temperature zones of the world between latitudes 30° and 45° North and South. The peach is round juicy fruit, which is yellow or furry red in colour with a fuzzy peel and has a large hard seed in centre. The shape of the fruit varies from beaked, round to flat. Peaches are classified into two types—freestone and clingstones—depending upon the flesh sticking to the stones or not. The fruit can be eaten raw and processed into different products. It is highly nutritious with a lot of phytochemicals, which are beneficial for health. Several studies have reported that these health beneficial characteristics are attributed to different bioactive components. The important bioactive compounds present in peach include phenolics, carotenoids and ascorbic acid. These compounds are responsible for antioxidant activity and thus helpful in preventing several diseases. The phenolic compounds that have been isolated and identified in peach fruits are categorized into anthocyanins, flavanols, phenolic acids and flavonols.

Keywords

Peach · Phytochemicals · Antioxidant activity · Phenolic acids · Anthocyanins

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23.1 Introduction

Botanical Name: *Prunus persica* (common name: Aurka).

Peach is a round juicy fruit which is yellow or furry red in colour with a fuzzy peel and has a large seed in centre. The fruit is grown at warm places of temperate zones having latitudes between 30° and 45° North and South (Hancock et al. 2008). Peach fruit comes under drupes or stone fruits as its mushy flesh surrounds a shell containing an edible seed. The shape and size of the fruit vary from beaked, round to flat. The fruit itself can be eaten raw or it can be added to a variety of dishes. It is highly nutritious and is loaded with goodness of phytochemicals helping in health issues, including digestion, skin problems and allergy. The peach fruit trees may be easily grown through seeds and fruits can be preserved for longer time. The peach fruits have now become a leading deciduous fruit crop grown and it is estimated that demand for locally produced peaches is high and thus the future is brighter for growers.

23.1.1 Classification

The taxonomic classification is displayed in Table 23.1.

23.1.2 Nutritional Profile

The peach fruit is packed with a lot of nutrients and antioxidants. The peach contains 89% water, 14% carbohydrates, 1% protein and a negligible amount of fat (Table 23.2). Peach fruit has a glycaemic index of 5, which are nearly equal to fruits with less sugar. The peach has a good amount of polyphenols, out of which the important phenolic compounds are chlorogenic acid, catechins and epicatechins. The flavonoids present in clingstone peaches are rutin and isoquercetin. Peaches are also

Table 23.1 Taxonomic classification of *Prunus persica*

Kingdom	Plantae
SubKingdom	Tracheobionta
SuperDivision	Spermatophyte
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Rosidea
Order	Rosales
Family	Rosaceae
Subfamily	Prunoidae
Genus	*Prunus*
Species	*Persica*

Source: Kant et al. (2018)

Table 23.2 The nutritional composition of peach

Nutritional component	Amount
Calories	58
Protein	1 g
Fat	<1 g
Carbohydrates	14 g
Fibre	2 g
Vitamin C (ascorbic acid)	17% of daily value
Vitamin A (retinol)	10% of daily value
Potassium (K)	8% of daily value
Niacin	6% of daily value
Vitamin E (tocopherol)	5% of daily value
Vitamin K	5% of daily value
Copper (Cu)	5% of daily value
Manganese (Mn)	5% of daily value

rich in anthocyanins and carotenoids, which are helpful in diseases prevention closely in association with reduction of oxidative stress like cancer, atherosclerosis, cataracts and ageing. Peaches are of great commercial importance and have a peculiar flavour as well as aroma resulting from the balance of organic acids, polyphenolic compounds, sugars, carotenoids and volatile compounds. The consumption of fruit has increased due to consumer knowledge about the nutritional composition and the potential sources of functional foods.

Apart from nutrient benefits, peach also provides a good amount of soluble and insoluble fibre in diet. Insoluble fibre helps in peristaltic movements and thus relives constipation and adds satiety to the diet, while insoluble fibre is the food for gut bacteria, thus elevating the release of short chain fatty acids like butyrates and propionates that feed the gut cells.

The fruit having good flavour and shape with a high amount of sugar content is desired by consumers. The fruit should have low to moderate acidity for fresh produce, but on the other hand the processed fruits should be firm with no tip on the pit, vibrant colour and flesh without browning.

23.1.3 History

Peach has originated in China 8000 years back although it was thought that peach is native to Persia. It has been mentioned in Chinese writings and was domesticated 4000 year back. The variations in the peach cultivations are known to be found in Chinese races. Peach was introduced within Greece through Persia, and so to some extent it is known as persica fruit and thus was scientifically nominated as persica and later was brought in Rome. It was spread throughout the roman Empire and was so lately introduced in Europe by Alexander the Great. Peach arrived in Florida, Mexico, and South America by Spanish and Portuguese explorers. It was later spread to North America by Spanish monks in mid-1500 and was broadly spread around

Jamestown, Virginia, during 1607 native Americans. English explorer John Lawson in his writings in 1700 said that ‘Our land has been made a wilderness of Peach trees’. Today also the peach trees appear along roadside and fences in suburban backyards and old fields throughout the southeast. Spanish explorers are the ones who were responsible for introducing the peach to South America and after that it gradually became popular in England and France. At the times of queen Victoria’s rule, ‘no meals were said to be complete without the presentation of peach in fancy cotton cloth’. In the seventeenth century, horticulturist George Minifie, native of England, cast the first peach plants to the newer world colonies, which were planted in his estate in Virginia. American Indian tribes were helpful in the spread of peach trees in India. Commercial growth of peach is done in California, Washington, South Carolina, Georgia and Missouri. It has been a common fruit of Mexico and England since long. The countries in temperate zones are cultivating the peaches for centuries.

23.1.4 Production

The world production of peach has increased enormously from the beginning of the 1980s till today. The Food and Agriculture Organization (FAO) has recorded the spike in production from an average production of 9323 thousand tons in the time period between 1989 and 1991 to production of 11,065 thousand tons in 1998. The growth of peaches worldwide is 15,000,000 tons, out of which 50% of the production comes from Asia. Europe contributes for about 30% of the peach crop, while North America has 11%, South America 6% and Africa 5% (Sansavini et al. 2006). The main world production areas lying in the Mediterranean region are Italy, Greece, Spain, France and Turkey. Out of this, Europe has taken the 50% production charge and main producers from Europe are Spain and Italy. Spain stands at third position in terms of production of 1 million tons at European level. North America has a production around 1,600 thousand tons. The major production areas include Valle del Ebro, Lerida and Murcia.

From Table 23.3, it is clear that the production increase in the countries is stated between years 1998 and 1999 and South America shows a significant increase

Table 23.3 Worldwide production of peach

Country	Produce (thousand tons)		Percentage
	1999	1998	
Africa	804	832	7%
Asia	4601	4610	38%
Europe	3546	4183	35%
North America	1455	1484	12%
Oceania	104	107	1%
South America	774	825	7%

Source: Sansavini et al. (2006)

Table 23.4 Indian peach production in year 2015–2016

State	Production (tonnes)	Share
Uttarakhand	57.93	54.04
Punjab	31.32	29.21
Himachal Pradesh	8.03	7.50
Jammu & Kashmir	4.07	3.80
Haryana	3.50	3.26
Nagaland	1.94	1.81
Tamil Nadu	0.30	0.28
Sikkim	0.09	0.08

Table 23.5 Promising cultivars of major Indian regions producing peach

Fruit	Jammu & Kashmir	Himachal Pradesh	Uttar Pradesh
Peach	July elberta, Elberta, Peshawari, Quetta, Flordasum, Shan e Punjab, Sharbati	Alton, July elberta, JH Hale, Shan e Punjab, Sharbati, Burbank	Sharbati safeida Flordasun, Shan-e-Punjab

although the growth share is more for Asia and Europe. Europe was known to be the first importer of peaches having 683,529 thousand tons of import.

Peach grabs second place after apples in tonnage. *Prunus persica* is generally grown in West Asia, Europe, Himalayas and India with a height of 1000 ft. China, Italy, Spain and the United States are the major producers of the fruit. Prunus has approximately 200 sps. that are harvested for edible fruits and seeds. Mediterranean countries with Murcia region have extensive cultivation (Kant et al. 2018). Peach trees are highly sensitive to water clad soils and hence these trees should be grown in soils having good internal drainage for better and longer survival of peach trees. For this purpose the topsoil should be preferably sandy loam soil with the depth of at least 18–24 in, below which should be red-coloured well-drained clay soil. Both the topsoil and subsoil should have good fertility conditions with required nutrients for growth and should have good water-holding capability and must be permeable to the movement of water, air and roots. Also clean salt free water is required for the production of Peach. The irrigation water having sodium absorption ratio below 3 or total salts below 1000 ppm is appropriate to use. The peach production is still at a nascent stage in South America, but it is dramatically increasing in Brazil and Chile. The stone fruit production in India is in considerable quantity (Table 23.4).

A lot of labour is required for production of peach and that depends upon the size of orchard as well. Generally, there is a requirement of two persons for preparing land and plantation. The orchard requires mowing, application of pesticides and fruit thinning in the summer season and additional labour may be required during harvesting.

The main peach cultivars of colder region are July Elberta, Elberta, Peshawari, Quetta, Burbank and Stark Earliglo and low-chilling cultivars are Flordasum, Flordared, Shan e Punjab, Sharbati, and sunred that are popular in subtropical belts of Uttar Pradesh and Punjab (Table 23.5).

23.1.5 Botanical Description

The development of peach occurs from a single ovary, which results in fleshy juicy exterior edible part and a hard-stony interior part which encases the seed. Fertilization occurs in one of the two ovules present in ovary. Consequently, one half of the fruit is slightly larger than the other. The colour of the fruit flesh may be yellow, red or white. Shedding of fruits takes place naturally within 1 month after full bloom. The life span of peach trees is short as compared to other fruit trees. The orchards are planted again after every 8–10 years. Although trees can provide produce for 20–25 years, which is dependent on disease resistant, pest resistance and winter damage. The trees are intolerant to severe cold and so cannot be grown where temperature ranges from −23 °C to 26 °C. Pruning of trees is done annually to prevent them from becoming too tall; the upright shoots are back to outgrowing laterals to produce a spreading tree so that it can have more exposure to sunlight. There are thousands of peach varieties like Elberta, Redhaven and Halford, yellow and white fleshed types. Basically peaches are classified into two types, depending upon the flesh sticking to the stones or not:

(a) Freestone
(b) Clingstones

In freestones, flesh can be easily separated from the pit. In clingstones, fruit flesh sticks tightly to the stone. There are some varieties which fall under the variety 'semifree' which are partially freestone and clingstone. The freestone varieties are consumed as such while clingstones are processed and packed in cans.

The maturation of peach does not occur at once and harvesting is done 2–4 times, which in turn depends upon weather and location of fruit within a tree. Peaches are harvested on the basis of its firmness and colour. The tree ripe peaches are more in demand with high market price. The fruit should not be bruised or damaged during harvesting as it may cause early spoilage. Regulations can be enforced or voluntary programmes like Good Agriculture Practices (GAP) and Good Handling Practices (GHP) can be considered for better yield and quality. The main purpose of implementing these laws is to ensure food safety system and to avoid the contamination for foodborne illness. These programmes have a set standard for worker hygiene, manures and water qualities. The peach has become the most successfully bred tree fruit crop due to its relatively short juvenile period and easily made controlled crosses.

Annual pruning of trees is necessary for peaches due to its relation to bearing habit and they bear laterally on previous year growth. Pruning is also essential for getting new shoots on the wood for next year crops. There are certain production constraints which can be easily overcome with proper management. Peach plants are quiet sensitive to wet soil and so proper drainage of excessive water is required for plantation. Intercropping with other plants like vegetables is done, and the orchards are regularly irrigated to obtain optimum yield. Adequate amount of water is required during pit hardening and fruit maturation stage. A lack of irrigation system will lead to reduced fruit size. For raising rootstock, it is propagated through seeds. The seeds are kept in sand under moist conditions for around 3 months for stratification. Seeds are treated with thiourea or other recommended fertilizers for better germinations. The seeds are sown in seed beds, which are 5 cm deep and are 12–15 cm away from each other. The row-to-row spacing should be around 20 cm mulching with dry grass can be done by little water usage on sown beds. Grafting of peach plant can be done by a slant cut of 5 cm made on the 1-year-old rootstock, which is about 20 cm above the ground level. Another cut is made downward starting two-thirds from the top which forms a tongue-like structure on the rootstock. Similar cut is made on the bottom of scion that matches the cut made on rootstock. The size of tree varies from soil to soil and the existing climatic conditions. The size of the tree is medium in temperate zone and in plains the trees grow to the height of 6 m. The leaves are lanceolate or oblong lanceolate in shape. The margins of leaves are serrated, and the lamina is glossy on the top and light green on the bottom side. Flowers are solitary with pink colour and appear before leaf emergence. The flowers are pollinated by insects. Flowering starts in first week of February. Peach fruit is drupe type with epicarp and mesocarp as edible portions. Endocarp is hard stony which contains seed in it. The peach tree starts giving fruits in 3–4 years of plantation and optimum yield is obtained after 5–6 years. The life span of trees varies from 15–20 years in Indian conditions. Flowers bloom in spring season. And harvesting is done in the month of June and July. The harvesting is done for hard fruits and the quality improves after harvesting. The ripening also occurs in storage conditions. The commercial yield of fruits varies from 60 to 80 kg per tree annually. The foliar spray of 1% calcium nitrate results in increased firmness of fruit and shelf life can be increased up to 10–15 days.

23.2 Antioxidant Properties of Fruit, Juices, Seeds, Peels, Wastes and Its Products

Peaches are a rich source of nutrients and these nutrients are responsible for various health-promoting effects. Several studies have reported that these health beneficial characteristics are attributed to different bioactive components which possess antioxidant properties (Crozier et al. 2009; Noratto et al. 2009; Zhao et al. 2015).

Antioxidants are substances which prevent the oxidation reactions and work in different ways. Therefore, if the antioxidant capacity of a substance is to be determined, it cannot be done by a single method. Numerous methods have been developed to depict the antioxidant capacity of substances such as total phenolics (TP), 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical quenching assay, ferrous chelating capacity, trolox equivalent antioxidant capacity estimation (TEAC), oxygen radical absorbing capacity (ORAC), total radical trapping antioxidant parameter (TRAP), ferric ion reducing antioxidant power estimation (FRAP) and 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid (ABTS) estimation. The methods have been used to assay the antioxidant capacity of various food items, plant extracts and other valuable products. But the most important and widely used methods to evaluate the antioxidant capability are TP, DPPH and FRAP assay (Zhang et al. 2015).

Several studies have indicated that phenolic compounds present in peaches contribute to their antioxidant capacities (Tomas-Barberan et al. 2001). The another compounds responsible for antioxidant activity in peaches are ascorbic acid (AA) and carotenoids (Tomas-Barberan et al. 2001; Byrne 2002; Gil et al. 2002; Carbonaro et al. 2002).

Gil et al. (2002) reported that the TP content varied from 28 to 111 mg/100 g and from 21 to 61 mg/100 g for white- and yellow-fleshed fresh peaches, respectively, belonging to California cultivars. Proteggente et al. (2002) observed 38 mg/100 g of TP content in European cultivars, while Goristein et al. (2002) reported the amounts of 240 mg/100 g for pulp and 470 mg/100 g for peel for a Spanish peach cultivar. According to Stojanovic et al. (2016), the peel and pulp extracts exhibited a high value of TP content, varying from 44.2 to 211.4 for peel extracts and from 11.1 to 128.5 mg GAE/100 g fresh weight for pulp extracts. This high concentration of phenolic compounds was shown to be responsible for its high antioxidant capacity. Phenolic acids, a class of phenolic compounds, has been shown to be potent antioxidants. Ding et al. (2020) reported that phenolic acids were 26.11–62.73 mg/kg for different peach varieties grown over two different seasons. The polyphenolic acids include neochlorogenic acid and chlorogenic acid.

Gil et al. (2002) reported that the AA content of various California peach cultivars ranges from 6 to 9 mg/100 g and from 4 to 13 mg/100 g in white and yellow pulp fresh peaches, respectively. In other study, Carbonaro et al. (2002) reported that AA content of 5–6 mg/100 g was observed in European peach cultivars.

The total carotenoids content ranged from 7 to 20 mg/100 g for white-fleshed and from 71 to 210 mg/100 g for yellow fleshed peach cultivars (fresh weight). β-Carotene was observed in high concentration while as α-carotene and β-cryptoxanthin were present in small quantities (Gil et al. (2002).

23.3 Characterization of the Chemical Compounds Responsible for Antioxidant Properties

Phenolic compounds contain a large portion of secondary metabolites belonging to plant kingdom. Several thousand phenolic compounds are being identified in different plant species. Their distribution and accumulation in plants are controlled by both genetic and environmental factors (Crozier et al. 2009; Del Rio et al. 2013). Thus, the distinctive phenolic profiles may be used as taxonomic markers (Zhao et al. 2015).

Currently, 33 phenolic compounds are isolated from peach and were identified and categorized into anthocyanins, flavones, polyphenolic acids and flavonols. It has been reported that the phenolics content in the pulp is lower than that in the outer pericarp (Chang et al. 2000; Tomas-Barberan et al. 2001).

Ding et al. (2020) reported that the Catechin, Procyanidin B1, neochlorogenic acid and chlorogenic acid were present in greater concentration in peach fruits.

Senica et al. (2017) stated that chlorogenic acid, neochlorogenic acid, catechin, epicatechin and proanthocyanidin were present in large quantities in pulp and peel. Also, kernel of the fruit showed good content of TP ranging from 654.67 μg/g to 684.70 μg/g for two peach cultivars. The polyphenolics present were hydroxycinnamic acids, hydroxybenzoic acids, flavonols, flavanols, flavanones, flavone and dihydrochalcone.

According to Stojanovic et al. (2016), there is a significant difference between the phenolic compounds present in pulp and peel of peaches. The compounds like chlorogenic, neochlorogenic and p-coumaric acids are present in pulp, whereas several flavonol glycosides, in addition to chlorogenic, neochlorogenic and p-coumaric acids, are present in peel.

23.4 Health Benefits

Peaches can be eaten fresh or used in preparation of various dishes. They are rich in health-promoting nutrients such as vitamins, minerals and other bioactive compounds. They are rich in dietary fibre, which may contribute to healthy digestion. They contain compounds that may help in reducing risk factors for cardiovascular disease, such as hypertension, as well as triglyceride and cholesterol levels. They may help lower your immune system's response to allergens, thus reducing allergy symptoms. They may boost immunity, rid the body of toxins and reduce blood sugar levels.

The important health-promoting effects of peaches are associated with various bioactive compounds which act as natural antioxidants. These compounds act against free radical species which are responsible for destruction to DNA, proteins and fats. Researchers have revealed that these known compounds help to provide relief in several diseases such as heart diseases, cancers and ageing-related problems. For example, chlorogenic and neochlorogenic acids were reported to prevent breast cancer, while β-carotene prevents lungs and colorectal cancer (Fraser and Bramley 2004; Noratto et al. 2009). Cyanidin 3-glucoside present in peaches prevents cancerous growth in vivo and also prevents invasion by inhibiting metalloproteinases (Chen et al. 2006). Metalloproteinases play an important role in diminishing the extracellular matrix, which facilitates tumour invasion and metastasis. Precursors of vitamin A, such as carotenoids, β-carotene, α-carotene and β-cryptoxanthin, are present in peaches. This vitamin is important for normal vision and its deficiency can result in various ocular disorders (Fraser and Bramley 2004).

Peach fruits are rich in polyphenols, which possess anti-obesity properties. This may be due to alteration of the intestinal microbiota by polyphenols. Some studies have shown that peach extracts possess antiallergic inflammatory properties (Elsadr and Sherif 2016).

23.5 Conclusion

Peach is a round juicy fruit which is yellow or furry red in colour with a fuzzy peel and a large seed in centre. They are a rich source of nutrients responsible for various health-promoting effects. Peaches can be eaten fresh or used in preparation of various dishes. They contain various compounds which have bioactive components such as phenolic compounds, ascorbic acid and carotenoids. About 33 polyphenolic compounds were isolated and identified in peaches, and categorized into anthocyanins, flavones, polyphenolic acids and flavonols. These compounds may help to reduce risk factors for several diseases. They may help to reduce allergenic reactions, boost immunity, reduce body toxins and decrease blood sugar levels.

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Jackfruit (*Artocarpus heterophyllus*) 24

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Abstract

Artocarpus heterophyllus Lam., colloquially known as jackfruit, belonging to Moraceae family, is a potent storehouse of highly active nutrients such as carbohydrates, proteins, vitamins, minerals, and phytochemicals. Jackfruit is also known for its high therapeutic properties, which are well documented in Indian medicine systems such as Ayurveda, Siddha, and Unani. Almost all plant parts such as root, bark, sap, fruit, leaves, fruit, and seed possess high medicinal properties. Various studies on different constituents of the jackfruit proves that it possesses anti-inflammatory, antidiabetic, antifungal, antibacterial, anthelminthic, antihypertensive, and antiaging properties. Similarly, many parts of the plant have been reported for the use of topical application for skin ailments, wound healing, and poisonous bites. On the other hand, it is observed to have highly bioavailable form of phytonutrients. Jackfruit is one of the rare fruits which is rich in B complex vitamin, especially containing significant amounts of vitamin B6 or pyridoxine, riboflavin, niacin, and folic acid. It is also rich in carotenoids such as beta-carotene, neoxanthin, and zeaxanthin, which make it an excellent source of vitamin A. High amounts of phenolic and flavone compounds of jackfruit make it an antioxidant-rich fruit. Jacalin, one of the major and prominent proteins present in the jackfruit, has unique immunomodulatory effects which assist in alleviating the complications from various immune-related disorders. These attributes make jackfruit wholesome functional food.

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By-products of jackfruit such as its shaft, skin, latex, and seeds are widely used in the production of various value-added products such as edible cutlery, edible films, leather, and bakery products such as cookies, waffles, and cones. However, the jackfruit is still underutilized owing to its higher inedible portion and difficulty in peeling.

Keywords

Jackfruit · Anti-inflammatory · Antidiabetic · Antifungal · Antibacterial · Anthelminthic · Antihypertensive

24.1 Introduction

Jackfruit (*Artocarpus heterophyllus*) is native to tropical Asia, especially originated from the rainforests of the Western Ghats of India. It is also indigenous to Malaysia and grows in several regions of southeast Asia such as Bangladesh, the Philippines, Thailand, and Sri Lanka. Moreover, it is considered as the national fruit of Bangladesh and is locally termed as "kathal." The poorer sections of people in the jackfruit-growing areas consume it as a one-time daily meal instead of rice, and thus the fruit is familiarly known as "The poor man's food" (Rahman et al. 1995). Humid tropical lowland conditions are suitable for jackfruit growth. However, it is observed that altitudes such as 1300 m (in elevation) or around 1600 m also support its cultivation. Geographically, it fruits at latitudes of 30°N and S in areas which are generally frost-free, and it bears excellent crops between latitudes of 25°N and S. It is found to be intolerant to drought and excessive flooding conditions.

Especially in India and Bangladesh, it is mostly prepared as a meat substitute, owing to its appearance, meaty texture, and taste. On the other hand, the mature fruit is consumed fresh or processed into various fruit preserves such as jam, jelly, chutney, and paste, whereas the fruit pulp is used to flavor ice cream and beverages. Seeds of jackfruit are found to be a good source of dietary fiber and are edible upon processing, such as boiling, roasting, or drying. Thus, every part of the jackfruit tree is used apart from the whole plant. Similarly, pulp, seed, leaves, roots, and latex are used for either human consumption, as fodder, or for various medicinal purposes.

Jackfruit (*Artocarpus heterophyllus* Lam.) production was estimated at 3.7 million tons during 2015–2017 in the world. While its average output in India, Bangladesh, and Indonesia was accounted for 1.8 million tons, 1 million tons, and 700,000 tons, respectively, it is worthy to note that jackfruit was recorded as one among the largest exported minor fruits of Thailand.

24.1.1 Botanical Description

Jackfruit (*Artocarpus heterophyllus*) is a tropical composite fruit of family: mulberry (Moraceae), class: Magnoliopsida, subclass: Dilleniidae, order: Urticales. It is the largest edible fruit (Goswami et al. 2011) in the world, barrel or pear-shaped, varying

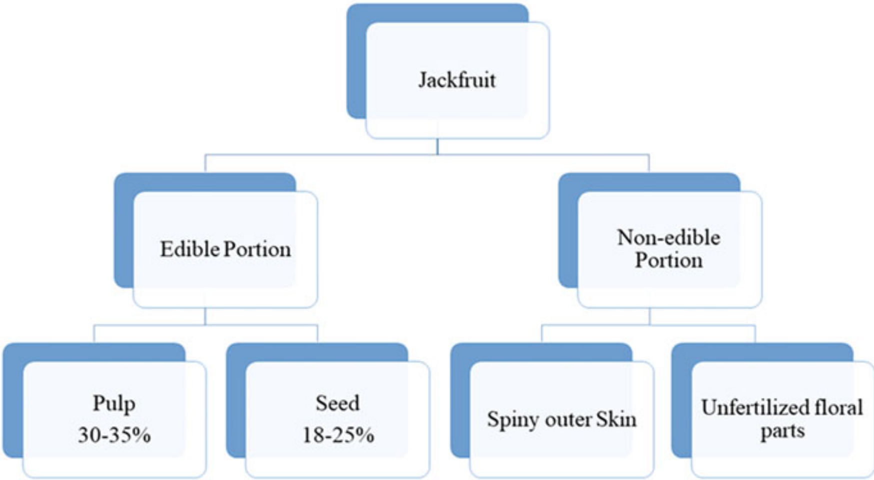

Fig. 24.1 Edible and non-edible portions of jackfruit

in color in between green and golden-yellow, having short pyramidal warts (30–100 × 25–50 cm) (Naik 1949), and weighing in between 2 and 36 kg (Mahanta and Kalita 2015). Jackfruit being composite fruits, consist of edible and nonedible portions, as shown in Fig. 24.1 (Madrigal Aldana et al. 2011; Mahanta and Kalita 2015). The jackfruit is composed of fruit axis, pulp, flake, and peel. Briefly, the fruit axis (inner core), the pulp (middle bulb portion which is edible), the flake (outer packaging portion), and the peel (outermost thorny inedible part) are the essential parts of jackfruit. Apart from the axial part of the fruit and the peel, the fruit is consumed as a vegetable and fruit in unripened and ripened stages, respectively (Ong et al. 2006). The seeds of jackfruit are smooth, oval, light-brown colored, may vary from 2 to 4 cm in length, and a single fruit may enclose about 100–500 seeds that account for about 18–25% of the total fruit weight. Despite being of large size, these seeds are edible, and these are basically enveloped in aril encircling a spermoderm, which is in turn is covered by cotyledon. Jackfruit has been in limelight in the recent past owing to extensive research carried out on it and it is explored as the underutilized crop having greater potential value.

The texture of the jackfruit is found in two forms: one is **Ghila** having soft and pulpy perianth, with juicy pulp, and small seeds; the other is **Khaja** (karcha) with firm perianth, not very juicy, and large seeds. In addition to these two, another texture recognized as *dorosha* having mixed characteristics of both *khaja* and *ghila* (Morton 1987; Goswami and Chacrabati 2016). Generally, the tree reaches a height of 8–30 m, having a trunk diameter ranging from 30 to 200 cm. While the main trunk and mature branches bear the fruit, it can also be found at the base of the tree. Stems are usually straight and rough in texture, having scaly bark. The tree bears evergreen, glossy, leathery leaves, measuring up to 22.5 cm long (Morton 1987). Moreover, white latex is produced from almost all parts of the plant, which is characteristically sticky. The tree is monoecious, and the inflorescence is a spike (Morton 1987), and it takes 3- to 7-months' duration from pollination to fruit development (Baliga et al. 2011).

24.2 Antioxidant Properties

Studies have shown that free radicals of oxygen and reactive species of oxygen and nitrogen have a profound impact in enhancing the toxicity, thereby causing the cell and tissue damage. Free radical and ROS formation occurs continuously in the body due to enzymatic and nonenzymatic reactions. In contrast, external agents like X-ray, ozone, and other air pollutants also act as potential sources of the same (Basu and Maier 2016). ROS, in general, is the usual metabolic component of the human body, but in case if it is present in excess quantities, then it can lead to damage in the protein, DNA, and various other macromolecules present. It can also become the root cause of many chronic diseases like heart-related problems, weakening of immunity, aging, diabetes, etc. (Ames et al. 1993; Kaneto et al. 2010). Antioxidants are the compounds inhibiting oxidative damage caused by the free radical species and thus play a pivotal role in the prevention of chronic diseases and neurodegenerative disorders like cancer, atherosclerosis, diabetes, cirrhosis, etc. The synthetic antioxidants like butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) pose a risk of certain side effects due to their toxic behavior in certain food applications alongside high manufacturing costs (Soong and Barlow 2004). Hence, natural phytochemicals and antioxidants have gained the attention of worldwide scholars, scientists, researchers, and consumers to lessen the risk of the aforementioned diseases and promote individual health, which is derived primarily from fruits and vegetables (Kaur and Kapoor 2001). Researches have been carried out on a wide scale all over the world to analyze the antioxidant properties of various fruits and vegetables, their parts like root, seeds, peel, bark, leaves, etc. (Grimm et al. 2004; Arabshahi-Delouee and Urooj 2007; Srinivasan et al. 2007). Antioxidant activity in the various parts of pomegranate (Li et al. 2006), potato (Mohdaly et al. 2010), quince fruit (Silva et al. 2004), tamarind (Martinello et al. 2006), grapes (Kanner et al. 1994), orange (Liu et al. 2010) along with many others. In the following sections, the emphasis is laid on the antioxidant properties of parts of jackfruit.

24.2.1 Method of Extraction

To conduct the experiments, fruits were frozen as a whole and then subsequently thawed. Various segments of the fruit, namely skin, seeds, and pulp, were separated manually and then lyophilized. Small amounts (1–2 g) of each of the lyophilized fruit samples were made homogeneous using mortar and pestle using suitable solvents to finally obtain the antioxidant assays, which were then stored at low temperatures under vacuum packaging. This detailed procedure for the extraction of fruits for antioxidant assays was as followed by Soong and Barlow (2006).

Furthermore, it should be noted that there exists no specific methodology for the determination of the total antioxidant activity of fruits and vegetables or their respective plant parts. Hence, to determine their antioxidant properties, in general, they are tested against DPPH radical, DMPD radical, and observe the extract's ferric reducing strength, where DPPH stands for 1, 1-diphenyl-2-picrylhydrazyl, FRAP stands for ferric ion reducing/antioxidant potential, and DMPD stands for *N, N*-dimethyl-*p*-phenylenediamine. These methods and obtained antioxidant properties are discussed in detail in later sections corresponding to each of the fruit parts.

24.2.2 Pulp

The jackfruit pulp (JFP), owing to its high nutritive value, is eaten as a salad and in cooked state. The table below elaborately demonstrates the nutrient composition in every 100 g of ripe fruit pulp. In addition, the pulp contains a high moisture content of 77% and 84 calories per 100 g of the ripened pulp (Samaddar 1985). Jackfruit is a rich source of antioxidant compounds alongside several carotenoids, which sum up to 14 in number. In spite of the soft color of the jackfruit pulp, lycopene was discovered in the JFP (Setiawan et al. 2001). Therefore, the processed pulp has wide applications for commercial production of jam, jellies, candies, juices, pickles, cookies, pastes, leather, chips, etc.

Primarily, the phenolic compounds and the flavonoid molecules constitute an important fraction toward the resultant antioxidant capacity of the sample which can also be calculated individually. Phenolics acts as dietary antioxidant compounds portraying the mechanism for retarding the production of reactive species during metabolism of living cells and thus preventing any damage caused to them (Shrikanta et al. 2015). Different solvents like acetone, water, ethanol, and methanol were evaluated for the most suited extraction of phenolic and flavonoid contents. According to the data obtained, ethanol contributed the most (0.46 ± 0.014 mg GAE/g) in the extraction of total phenolics whereas water (1.20 ± 0.020 mg RE/g) for extraction of total flavonoids (Table 24.1).

Table 24.1 Nutrient composition of the jackfruit pulp/100 g

Nutrient composition of pulp	Quantity/100 g
Carbohydrate	18.9 g
Protein	1.9 g
Fat	0.1 g
Fiber	1.1 g
Total mineral content	0.8 g
Calcium	20 mg
Phosphorus	30 mg
Iron	500 mg
Vitamin A	540 I.U.
Thiamin	30 mg

Source: Setiawan et al. (2001)

Jagtap et al. (2010) analyzed the total antioxidant properties of the extracted pulp using the three aforementioned methods. DPPH method revolves around the concept of quantifying the antioxidant activity by measuring the proton radical scavenging efficacy present in the assay. Antioxidant compounds present in the pulp leads to fading of the deep violet color of the DPPH solution.

$$\text{DPPH scavenging activity }(\%) = \frac{\text{Control absorbance} - \text{Sample absorbance}}{\text{Control absorbance}} \times 100$$

FRAP is an uncomplicated, economical, and direct process for calculating total antioxidant potential of the required sample. The JFP extract at different concentrations reduced the ion from ferric (Fe^{+3}) to (Fe^{+2}) accordingly. This radical scavenging ability gets higher with an increase in concentration. The reducing power decreases if the fruit is further left for ripening (Harris and Brannan 2009). The protocol usually followed is as stated by Hossain et al. (2014).

DMPD is a quick, cost-effective method with a comparatively stable endpoint. The antioxidant compounds cause a discoloration of the colored $DMPD^{+}$ and are in a directly proportional relationship with the concentration of JFP in the extract. The study showed that all the extracts have the potential to demonstrate antioxidant capacity in the decreasing trend of methanol, ethanol, water, and acetone.

In another similar research, resveratrol content and antioxidant characteristics of several underutilized fruits were determined including *Artocarpus heterophyllus.* Resveratrol is a phenolic compound responsible for attenuating the lipid metabolism and impede the oxidation of low-density lipoproteins and clustering of platelets (Frémont 2000). The antioxidant property is studied using the aforementioned discussed DPPH method wherein radical scavenging activity was calculated by taking the absorbance reading A_S and ADPPH at 517 nm using the formula:

$$\text{Radical scavenging activity }(\%) = \frac{\text{ADPPH} - \text{AS}}{\text{ADPPH}} \times 100$$

Total polyphenols (expressed as gallic acid equivalents GAE), flavonoids (expressed as (+) − catechin equivalents, DPPH IC_{50} value (amount of sample required to inhibit 50% of DPPH radicals) and total antioxidant capacity (expressed as gallic acid equivalents) of JFP extract in three different analyses were found to be $1.27 \pm 0.33\,^{f}$ mg $GAEg^{-1}$ dry weight, 0.11 ± 0.03^{c} mg CEg^{-1} dry weight, 11.45 ± 0.46^{b} mg ml^{-1}, and $3.25 \pm 0.25^{a,b}$ mM GAE g^{-1}, respectively (Shrikanta et al. 2015).

Basu and Maier (2016) conducted a study for determination of the in vitro antioxidant potential of a few commercial fruits wherein the total phenolic content of jackfruit was found to be more than that of blackberry, strawberry, and California table grape, whereas lesser than that of blueberry, red raspberry, and black raspberry. However, the DPPH radical scavenging activity of jackfruit was comparatively lesser than that of blackberry, strawberry, and California table grape.

In yet another study, antioxidant properties and the phenolic content of the edible portions of various fruits such as mango, avocado, tamarind, and jackfruit were determined for fresh and freeze-dried samples taking into consideration the wet and dry weight, respectively. The L-ascorbic acid–equivalent antioxidant capacity (AEAC) for the fresh sample was least for jackfruit and highest for tamarind. Comparatively, the same trend followed for the freeze-dried sample too.

24.2.3 Seeds

Jackfruit is a combination of several berries with brown seeds in a shell embedded within a yellow pulp. They have various phytonutrients like lignans, isoflavones, and saponins which are responsible for imparting the antihypertensive, antiaging, and antioxidant characteristics.

In general, fruit seeds are not popular unlike oil seeds and edible pulp of fruits due to lack of commercially viable products and applications, therefore, receiving not much attention from the consumers and researchers. As a matter of fact, not much research has been done on the antioxidant properties of subtropical and tropical fruit seeds, unlike oil seeds. However, on an industrial scale there is a large proportion of by-products during fruit processing, which is regarded as waste but if utilized efficiently can otherwise act as a rich source of natural food additives and ingredients. Studies have shown the antioxidant property of seeds of grape (Kim et al. 2006), mango (Maisuthisakul and Gordon 2009), flaxseed (Touré and Xueming 2010), and sesame (Shahidi et al. 2006).

In addition, it can also be observed that the seeds have much higher antioxidant quantities when compared with the edible portion. This inference can be taken from Table 24.2 (Soong and Barlow 2004). Numerous studies have been conducted on jackfruit seed starch and flour properties.

Table 24.2 Antioxidant activity of jackfruit seed and pulp

	Jackfruit seed	Jackfruit pulp
Fresh sample		
Antioxidant activity AEAC[a] (μmol g^{-1})	7.4 ± 2.0	3.0 ± 0.4
Freeze-dried sample		
Antioxidant activity AEAC[a] (μmol g^{-1})	25.4 ± 2.6	11.0 ± 0.3
FRAP[a] (μmol g^{-1})	2.8 ± 0.3	6.8 ± 0.5
Phenolic content GAE[a] (mg g^{-1})	27.7 ± 3.4	0.9 ± 0.0

Source: (Soong and Barlow 2004)

[a]Means of three determinations ± SD (standard deviation)

24.2.4 Peel

The peel comes under the outer thorny, nonedible part which compounds to be 46% of the total fruit. In general, it is mainly used as a fertilizer or disposed of as waste (Ding and Ming 2009). Due to sparsely available research on jackfruit peel and its phytochemical and biological activity, Zhang et al. (2017) were the first to conduct a study to examine and compare the polyphenol and antioxidant content, hypoglycemic activity of the fruit peel with the pulp, flake, and seed components. In this particular research, the DPPH and ABTS+ scavenging capacities were measured to determine the antioxidant potential. In addition, the total phenols and flavonoid content was analyzed alongside α-glucosidase inhibitory activity, for identifying the phytochemical profiles. The combined result of this study can be demonstrated in Table 24.3 (Zhang et al. 2017).

As we can see from the Table 24.3, the highest flavonoid and phenolic content can be derived from the peel extracts. The higher amount of polyphenol content in the jackfruit peel than even the pulp itself can be owed due to its direct contact with the external surrounding environment. This induces the abiotic stress factors like sunlight, UV rays, and temperature to cause accumulation of polyphenol in the peel. The similar type of results has been observed in other rinds or peels of fruits like pomegranate (Masci et al. 2016), quince fruit (Silva et al. 2004), etc.

In addition, flavonoids proved to be the dominant compounds present in jackfruit peel extract, with 18 different types of compounds found in peel extracts. The phytochemical profile characterized using HPLC-QTOF-MS/MS method resulted in identification of 53 different compounds.

24.2.5 Wastes

During export or other commercial-household purposes, the pulp gets segregated from the skin and is usually termed as waste. Daud et al. (2017) determined the antioxidant properties of jackfruit waste, which consists of rind and rachis. About half of jackfruit (50%) is rind and other unfertilized floral parts which are regarded as waste due to high fibrous content despite being rich in jackfruit flavor (John and

Table 24.3 Antioxidant activity comparison among the peel, pulp, flake, and seed (Zhang et al. 2017)

	Peel	Pulp	Flake	Seed
Total phenolics (mg GAE/g DM)	48.04 ± 4.57	10.34 ± 0.16	11.57 ± 0.06	9.71 ± 0.06
Total flavonoids (mg QuE/g DM)	2.79 ± 0.04	2.27 ± 0.31	2.29 ± 0.03	1.62 ± 0.10
IC50 value (mg DM/mL)	–	–	–	–
DPPH scavenging ability	1.25 ± 0.14	>10	>10	>10
ABTS$^+$ scavenging ability	0.23 ± 0.02	5.70 ± 0.37	8.21 ± 0.25	7.62 ± 0.13

Table 24.4 Antioxidant activity of the rind according to different extraction methods

		Maceration	Percolation	Soxhlet
	Yield of extractive substance (%)	28.0 ± 0.1	33.8 ± 0.1	12.1 ± 0.1
	Total phenolic content (mg GAE/g dry extract)	84.9 ± 0.1	79.5 ± 0.1	79.0 ± 0.1
RIND	Total flavonoid content (mg QE/g dry extract)	871.4 ± 1.2	511.6 ± 1.0	381.4 ± 1.1
	DPPH, inhibition (%)	94.4 ± 0.1	50.0 ± 0.1	43.0 ± 0.1
	FRAP (μm TE/ml of dry extract)	26.4 ± 0.7	24.6 ± 0.9	15.8 ± 0.5
	Beta-carotene (%)	59.0 ± 1.0	54.1 ± 0.3	25.3 ± 0.4

Table 24.5 The antioxidant activity of the rachis according to different extraction methods

		Maceration	Percolation	Soxhlet
	Yield of extractive substance (%)	29.0 ± 0.1	43.9 ± 0.1	16.3 ± 0.1
	Total phenolic content (mg GAE/g dry extract)	77.2 ± 0.1	74.0 ± 0.1	73.5 ± 0.1
RACHIS	Total flavonoid content (mg QE/g dry extract)	660.9 ± 1.1	429.4 ± 1.1	300.6 ± 1.1
	DPPH, inhibition (%)	62.0 ± 0.1	44.0 ± 0.1	38.0 ± 0.1
	FRAP (μM TE/ml of dry extract)	18.7 ± 0.2	15.7 ± 0.3	15.6 ± 0.2
	Beta-carotene (%)	28.9 ± 0.9	25.2 ± 0.8	20.0 ± 0.5

Narasimham 1993). A study was therefore conducted to assess the antioxidant potential through DPPH radical scavenging activity, FRAP, and by β-carotene bleaching assays of rinds and rachis. The phenolic and flavonoid content was also determined by total phenolic content and total flavonoid content assays, respectively, and were subsequently compared with the total antioxidant potential. Extraction was done using maceration, percolation, and Soxhlet methods.

The highest yield of crude extract out of all extraction methods was found to be through percolation, followed by maceration, and the least was through Soxhlet extraction. The antioxidant activity of the rind and rachis extracts are mentioned in Tables 24.4 and 24.5, respectively (Daud et al. 2017).

From the Tables 24.4 and 24.5, it can be observed that since maceration process softens and breaks the cell wall for the feasible extraction of stored phytochemicals, it shows the highest antioxidant activity despite comparatively lower percentage yield of extracts. Hence the percolation and Soxhlet techniques are not as effective for extraction as the maceration technique. In addition, the higher total phenolic contents in the rind are because of greater formation of phenolic compounds, which is primarily a light-dependent process. It has been observed that phenolic acid groups are located in the outer segments of a ripe fruit due to the direct sunlight on the outer surface. It has already been reported that higher phenolic content significantly to the antioxidant (Hidalgo and Almajano 2017). Hence, it is inferred that different extraction techniques (preferably maceration) can be employed to convert jackfruit waste into an economic product rich in antioxidants (Daud et al. 2017).

24.2.6 Antioxidant Properties of Products Prepared from Jackfruit Waste

Jackfruit has been known for its low cost and easy availability in the season. However, post-harvesting and maturity, ripe fruits are left to deteriorate in the fields due to abundance, poor handling, and lack of storage space. Hence to curb the excess wastage, alternate methods to utilize the fruits were developed. Tropical fruits were usually used to produce wines, and, therefore, jackfruit wine was introduced to combat the losses produced by excess and overripe jackfruits. Jagtap et al. (2011) prepared and evaluated the jackfruit wine produced from jackfruit juice resulting in the development of a functional beverage whose total phenolic, total flavonoids, and antioxidant activity were analyzed. The total phenolic compound was found to be 0.053 mg GAE mL^{-1} while the total flavonoid compounds were 0.016 mg Rutin equivalent mL^{-1}.

24.3 Characterization of the Chemical Compounds Extracted from Jackfruits

There are several chemical compounds extracted from different parts of jackfruits which are responsible for antioxidant properties. The different parts of the jackfruit described in the sections above have been used as a substantial ingredient in Ayurvedic and Yunani medicine for a long time (Mukherjee 2001). The major contribution comes from phytochemicals like carotenoids, amino acids, flavonoids, and phenolics which have health-benefitting effects primarily due to their antioxidant properties. Natural antioxidants are known to curb the oxidation-induced damages caused in cell physiology and aging phenomenon occurring in the human body (Willett 2002). Phenolics and their metabolites are responsible for the inactivation of free radicals produced during lipid oxidation. It is also behind the provision of astringency in food products.

In its natural state, flavonoids are present as glycosides and aglycones in the tissues of fruits and vegetables. Flavanoids have a tendency to get oxidized to quinones and act as a free radical scavenger. Similarly, amino acid is also a kind of phytochemical known for its multiple functions by acting as a reactive oxygen species (ROS), free radical scavenger, and vitamin C activity. Various carotenoids such as β-carotene, lycopene, lutein, and zeaxanthin are also known to have antioxidant properties.

24.3.1 Free Radicals and Oxidative Stress Mechanisms

Basically, unpaired atoms or molecules or ions are termed as free radicals and they possess high reactivity during a chemical reaction toward other such particles. These are majorly derived from oxygen (O), nitrogen (N), and sulfur (S), and they give rise to various reactive chemical species namely reactive oxygen species (ROS), reactive

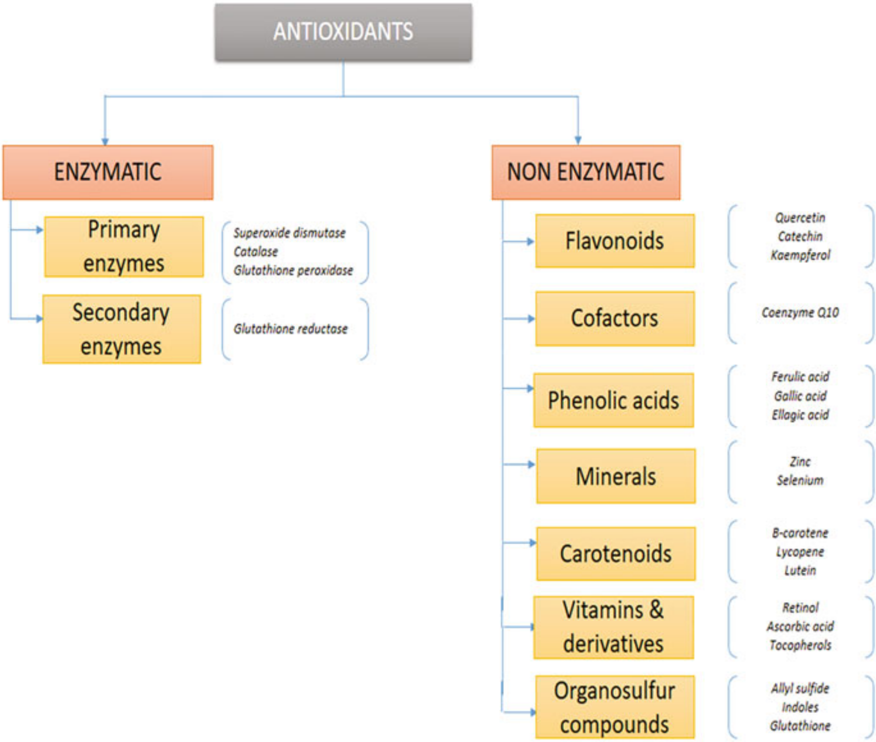

Fig. 24.2 Natural antioxidants separated into classes (Nimse and Pal 2015)

nitrogen species (RNS), and reactive sulfur species (RSS), respectively. Firstly, reactive oxygen species includes free radicals $O_2^{-\cdot}$, HO_2, OH, NO, and other species such as H_2O_2, singlet oxygen ($^1O_2$), HOCl, and $ONOO^-$. Reactive nitrogen species are generated by the reaction of NO with superoxide anion resulting in $ONOO^-$. Similarly, reactive sulfur species is obtained by the reaction of ROS with thiol (Lü et al. 2010). With time, a group of scientists has defined antioxidants through different definitions. According to Halliwell and Gutteridge (1995), antioxidants are “any substance that, when present at low concentrations compared with that of an oxidizable substrate, significantly delays or inhibits oxidation of that substrate” but later modified it as “any substance that delays, prevents or removes oxidative damage to a target molecule” (Halliwell 2007). Enzymatic antioxidants are classified as primary and secondary enzymes (Fig. 24.2) Nature has already imparted the necessary protective measures against free radicals, in the form of enzymes: **Glutathione peroxidase** donates two electrons for reducing peroxides and forms selenols simultaneously eliminating the substrate for Fenton reactions; **superoxide dismutase** responsible for converting superoxide ions into H_2O_2 as a substrate for another primary enzyme called catalase. The secondary enzyme defense mechanism involves **glutathione reductase** which reduces glutathione from its oxidized state to reduced state for it to continue the neutralization process of free radicals. **Thioredoxin**, **thiols**, and other disulfide bondings are among the other ones present in jackfruit cells as buffering systems.

The nonenzymatic antioxidants comprise of flavonoids, minerals, vitamins and derivatives, carotenoids, and phenolic acids. Vitamin C and vitamin E are also present in jackfruit and act as antioxidants (Fig. 24.2). Ascorbic acid has two compounds that demonstrate antioxidant property namely, L-ascorbic acid and L-dehydroascorbic acid. They are water-soluble and free radical scavenger absorbed in the gastrointestinal tract. About 100 g of jackfruit contains 12–14 mg of vitamin C, while the daily recommended dietary allowance for humans is 60 mg. It plays a significant role in scavenging the $O_2^{-\cdot}$, H_2O_2,.OH, $^1O_2$, and reactive nitrogen oxide (Barros et al. 2011). Likewise, vitamin E is a lipid-soluble, chain-breaking antioxidant having eight isoforms including four types of tocopherols (α, β, γ, δ) and four types of tocotrienols with α- tocopherols being the primary and most abundant.

The chroman head group of the tocopherol is responsible for its antioxidant property while the phytyl tail has no contribution in preventing the propagation of free radicals. Vitamin E inhibits peroxidation of lipids by transferring its phenolic hydrogen to the peroxy radicals which in turn forms tocopheroxyl radicals which are unreactive in nature.

Flavanoids is another group of antioxidants found in jackfruit comprising of flavanols, flavanones, flavones, anthocyanins, and isoflavonoids. All of these possess a common skeleton structure of $C_6C_3C_6$. The phenolic hydroxyl group bonded to the ring structure are accountable for the antioxidant property of the flavanoids. They act as hydrogen donators, singlet oxygen quenchers, and metal chelators. They also play a substantial role in activating the enzymatic antioxidants which are discussed above. In addition, they inhibit oxidases and reduce nitrosative stress (Procházková et al. 2011). Examples of some important flavonoids are quercetin (flavonol), catechin (flavanol), etc.

Phenolic acids are basically found in ester form and glycosides and have hydroxycinnamic acid and hydroxybenzoic acid. They play the role of chelators, with the free radical scavengers particularly targeting hydroxyl and peroxyl groups, superoxide anions, and peroxynitrites. The highest analyzed compound in hydroxybenzoic group and precursor of many tannins is gallic acid whereas cinnamic acid acts as the precursor for all types of hydroxycinnamic acids (Krimmel et al. 2010).

Carotenoids are the class of natural pigments generated exclusively by plant cells and microbes responsible for imparting the characteristic yellow-reddish color of many fruits, vegetables, and algae. They are categorized into carotenoid hydrocarbon (e.g., lycopene and β-carotene) and oxygenated carotenoids (e.g., xanthophyls). The carotenoids present in significant amounts in jackfruit are all-trans lutein (24–44%), all-trans β-carotene (24–30%), all-trans neoxanthin (4–19%), 9-cis neoxanthin (4–9%), and 9-cis violaxanthin (4–10%). In total, 18 carotenoids were successfully segregated and identified in jackfruit using HPLC, PDA, MS/MS technique (De Faria et al. 2009). Antioxidant potential of the carotenoids is because of singlet oxygen quenching which gives rise to exciting carotenoids dissipating their energy by interacting with the solvent, returning to the original stage and the cycle continues irrespective of the conjugated double bonds of carotenoids. The complete destruction of these pigments is only in the case of peroxyl radicals (Paiva and Russell 1999).

Jackfruit is also known to have minerals like selenium responsible for antioxidant properties. Despite their presence in trace quantities they are known to stimulate metabolism to a great extent. They themselves do not possess any antioxidant property but are quintessential for the working of antioxidant enzymes (e.g., metalloenzymes, glutathione peroxidase, thioredoxin reductase) in the human body. Another example of such a mineral is zinc (Prasad et al. 2004).

24.4 Health Benefits

High levels of low-density lipoprotein cholesterol (LDL-C) or/and decreased high-density lipoprotein cholesterol (HDL-C) led to dyslipidemia. It is one of the primary causes of cardiovascular disorder. Oxidation of LDLC causes atherosclerosis and cardiovascular disease by rendering the lipoprotein atherogenic. Excess oxidation in the vasculature reduces vasodilator nitric oxide level, increases tissue injury, oxidation of protein, and leads to DNA damage along with inducing pro-inflammatory responses. The benefit of jackfruit is through functional components like phenolic extract and prebiotic. It improves microbial balance in the intestine. Potassium, sodium, and vitamin B6 in jackfruit is a remedy for cardiovascular and bone loss, and they improve muscle and nerve function (Esmaillzadeh and Azadbakht 2008; Heinecke 2006).

Likewise, skin health deteriorates because of the natural aging process, including ultraviolet radiation causes an adverse effect to the skin, oxidative stress, sunburn, premature skin aging, immune suppression, and skin cancer. Gluten-free, casein-free jackfruit containing antioxidant and vitamin C possesses systemic anti-inflammatory benefits to the skin (Widmer et al. 2006; Swami et al. 2012). Jackfruit is also influential in the treatment of stomach ulcers. Commercially available antiulcer drugs for the treatment of stomach ulcer have several side effects, such as H_2 receptor antagonists may induce gynecomastia and galactorrhea in men and women, respectively. But the traditional remedy for ulcer treatment with no side effects has been proven to be jackfruit. In addition, the presence of dietary fiber in the jackfruit aids in easier bowel movements and thus assists in prevention of constipation (Table 24.6).

It also removes carcinogenic chemicals from the colon, thus providing protection against colon mucous (Siddappa 1957). Also, bone-related problems like osteoporosis are one of the diseases prevailing among a large population. Jackfruit being rich in magnesium helps in the absorption of calcium, helping in strengthening the bone and prevents osteoporosis. High iron contents in the jackfruit provide a remedy to anemia and also improves blood circulation (Singh et al. 1991). Similarly, copper and microminerals in the jackfruit play a vital role in ensuring healthy thyroid gland metabolisms like hormone production and absorption (Gunasena et al. 1996).

Table 24.6 Antioxidants and their effects on diseases

Disease	Antioxidants	Effect
Gastric cancer	Vitamin E, β-carotene, selenium	Decrease
Lung cancer in smokers	Vitamin E, β-carotene, and both together	No significant effect
Prostate cancer	Vitamin E	Decrease
Lung cancer in workers exposed to asbestos	β-carotene + vitamin A	No significant effect
Coronary heart disease, atherosclerosis	Vitamin E	Decrease
Hypertension	Vitamin C	Decrease
Diabetes/hyperglycemia	Vitamin C	Restores
Type 2 diabetes	Vitamin E	No significant increase
Pre-eclampsia	Vitamin C (1000 mg) + Vitamin E (400 mg) during pregnancy	Decrease

Source: (Devasagayam et al. 2004; Swami et al. 2012)

24.5 Conclusion

Jackfruit is a rich source of beneficial nutrients, whereas its by-products were also found to have application in baked products such as cookies owing to their functional benefits. However, jackfruit is considered as underutilized due to factors such as its lack of value addition and commercialization of its value-added products. Numerous research evidences support the various health beneficial claims of jackfruit that protect against various ailments.

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Cranberry

25

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Abstract

The present chapter describes the botanical origin of different species of *Vaccinium*, along with the chemical composition and properties of these plants. Cranberries are cultivated on large areas, and the fruits are indispensable in nutrition. They are always present in traditional celebrations in different countries. Due to the fact that the fruits of *Vaccinium* are boosters of vitamins, minerals, and biologically active compounds, increased attention was given to the bioactive properties related to the phytocompounds. Vitamin C, flavonoids, phenolic acids, proanthocyanins, and carotenoids are the principal substances that exhibit the antioxidant activity, controlling the urinary tract disease, glucose level, heart health, and antibacterial and anticancer diseases. Numerous scientific studies describe in detail the benefits as well as the mechanisms of action on the mentioned diseases. In conclusion, cranberries, from different *Vaccinium* species,

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are healthy fruits with high nutritional value and benefic phytochemicals fighting against different diseases.

Keywords

Cranberry · Vitamin C · Phenolic acids · Antioxidant activity · Health benefits

25.1 Introduction

25.1.1 Botanical Name, Common Name

Cranberries are a group of evergreen shrubs, which are known and exploited mostly for their fruits (berries) in Great Britain, North and South American continent, and Europe. Besides the wild species, which are used for different purposes, nowadays cranberries are also cultivated in the United States, Canada, Chile, central and northern parts of Europe, Australia, and New Zealand. Cranberries belonging to *Vaccinium* genus, subgenus Oxycoccos, are related to blueberries, bilberries, and huckleberries.

Taxonomy:
Kingdom: plantae
Order: Ericales
Family: Ericaceae
Genus: Vaccinium
Subgenus: Oxycoccos

Due to the fact that the geographical distribution on the globe is very large, and different subgenus grow in different climate and land conditions, the *Vaccinium* genus, subgenus Oxycoccos, may be described as cranberry (American cranberry, European cranberry, large cranberry, small cranberry, northern cranberry); although the names are similar, despite the fact they belong to different sections of the mentioned subgenus. The name cranberry was first given by the Germans and the Dutch (*kranebere*) because their flowers resemble with the head of a crane (Fig. 25.1). In 1647, John Eliot named the plants and berries as *cranberry* for the first time (The Cranberry Institute 2018).

The taxonomy of the genus *Vaccinium* is complex and far from being precisely classified. One of the classifications divides *Vaccinium* genus into subgenera, and subgenera into different sections. For example, the subgenus *Oxycoccos* can be divided into section *Oxycoccos* (*V. macrocarpon*, *oxycoccos*, *microcarpon*) and section *Oxycoccoides* (*V. erythrocarpum*). Furthermore, the subgenus *Vaccinium* can be divided into 20 different sections: *Batodendron*, *Brachuceratium*, *Bracteata*, *Ciliata*, *Cinctosandra*, *Conchophyllum*, *Cyanococcus*, *Eococcus*, *Epigynium*, *Galeopetalum*, *Hemimyrtillus*, *Koreanum*, *Myrtillus*, *Neurodesia*, *Oarianthe*, *Oreades*, *Polycodium*, *Pyxothamnus*, *Vaccinium*, and *Vitis-idaea* (*Vaccinium*).

Fig. 25.1 Cranberry (*Vaccinium oxycoccos*) flower. (© Copyright: Images: Jouko Lehmuskallio. All rights reserved)

Some species and common names of cranberry are presented in Table 25.1. As shown in the table, "cranberry's" common names have only the subgenus *Oxycoccos* and the section *Oxycoccos*.

Different species are known, native to different parts of the world, but only some of them are extensively studied and their nutritional and bioactive properties known. In this study, we will focus on the following ones:

- *Vaccinium oxycoccos* L. (European cranberry, common cranberry, northern cranberry), native to Great Britain, but with the greatest spread in the world; found also in North Asia and North America.
- *Vaccinium microcarpum* Turcz ex. Rupr (small cranberries), found in the northeast parts of the globe (deep north of Northern Hemisphere – China, Russia, and Scandinavian Peninsula).
- *Vaccinium macrocarpon* Ait (American cranberry, large cranberry), native to and cultivated in North America.
- *Vaccinium erythrocarpum* Michx (southern mountain cranberry), native to eastern Asia, Appalachian Mountains, and south of North America.

Table 25.1 Some species of the *Ericaceae* family, *Vaccinium* genus, with edible fruits

Nr.	Genus and species	Common name	Geographic range
1.	*Vaccinium angustifolium* Ait.	Lowbush blueberry	Eastern North America
2.	*Vaccinium arbuscula* (A. Gray) Mart.	Dwarf bilberry	Western North America
3.	*Vaccinium arctostaphylos* L	Caucasian whortleberry	Southern Europe
4.	*Vaccinium ashei* Reade	Rabbiteye blueberry	Southeastern USA
5.	*Vaccinium boreale* Hall & Ald.	Northern blueberry	Eastern North America
6.	*Vaccinium caesariense*	New Jersey blueberry	Eastern USA
7.	*Vaccinium caespitosum* Michx.	Dwarf bilberry	North America
8.	*Vaccinium consanguineum*	Costa Rican blueberry	Costa Rica
9.	*Vaccinium corymbosum* L.	Highbush blueberry	Eastern North America
10.	*Vaccinium darrowii* Camp	Darrow's blueberry	Eastern North America
11.	*Vaccinium deliciosum* Piper	Cascade blueberry	Western North America
12.	*Vaccinium erythrocarpum* Michx.	Southern mountain cranberry	Eastern North America
13.	*Vaccinium hirsutum* Buckl.	Hairy blueberry	Eastern North America
14.	*Vaccinium koreanum*	Korean blueberry	China, Korea
15.	*Vaccinium macrocarpon* Ait.	American cranberry	Eastern North America
16.	*Vaccinium membranaceum* Dougl. ex Hook.	Mountain huckleberry	Western North America
17.	*Vaccinium moupinense*	Himalayan blueberry	Chinese Himalaya
18.	*Vaccinium microcarpon* Turcz ex. Rupr	Small bog cranberry	British Islands, Scandinavia, Asia, Nevada America
19.	*Vaccinium myrsinites* Lamarck	Evergreen blueberry	Southeastern USA
20.	*Vaccinium myrtillus* L.	Bilberry	Europe, Asia, North America
21.	*Vaccinium myrtilloides* Michx.	Canadian blueberry	North America
22.	*Vaccinium oxycoccos* L.	Small cranberry	Europe, Asia, North America
23.	*Vaccinium ovalifolium* Smith	Alaska blueberry	Western North America
24.	*Vaccinium ovatum* Pursh	California huckleberry	Coastal Western North America
25.	*Vaccinium parvifolium* Sm.	Red huckleberry	Madeira
26.	*Vaccinium pallidum* Ait.	Hillside blueberry	Eastern North America
27.	*Vaccinium praestans* Pamb.	Kamchatka bilberry	Eastern Asia
28.	*Vaccinium tenellum* Ait.	Small black blueberry	Eastern North America
29.	*Vaccinium uliginosum* L.	Bog bilberry	Europe, Asia, North America
30.	*Vaccinium vitis-idaea* L.	Lingonberry, Mountain cranberry	Europe, Asia, North America

Adapted from Hancock et al. (2003)

- *Vaccinium vitis-idaea* L. (lingonberry, bearberry, foxberry), is characteristic field-layer species, found in boreal forests, Nordic countries, and North of Russia. It is also found in Carpathian Mountains (Romania).

25.1.2 History

Cranberry fruits were known and used from ancient times. They are native to North America, but were harvested, used, and afterwards cultivated almost all over the world. People from Europe, Siberia, and North America were aware of the benefic actions of these fruits, and were using them to treat different diseases of those times: colds and flu, digestive and urinary problems (Česonienė and Daubaras 2016). Sailors of that time used these berries to prevent scurvy, the activity being demonstrated far later, when chemical composition of the fruit was determined, revealing high amounts of vitamin C (Schmidt 1977; Hancock et al. 2003; USDA 2008). In 1816, Captain Henry Hall started cultivating cranberry in Dennis Massachusetts, USA. The first large plantation was made near Boston in 1833 and continued to increase in the nineteenth century all over the United States (Eck 1990). Canada was following the cultivation, and large plantations were established from Nova Scotia, Quebec, to British Columbia. Nowadays, cultivated cranberries lie on an area of approximately 23.470 hectares, in Northern United States, Canada, and Chile.

25.1.3 Production (Native Country, World)

The two most important cranberry species, *Vaccinium macrocarpon* and *Vaccinium oxycoccos*, known by their common names American cranberry and European cranberry, are the most spread, both as native wild species and also as cultivated ones. The three major cranberry-producing countries in the world are the United States, Canada, and Chile. The global production fluctuates over the years, depending on climate or other conditions (Fig. 25.2). The most prominent cranberry-producing states in the United States are Wisconsin (~65% from US production), Massachusetts (~23% of the whole production), New Jersey, Oregon, and Washington (US Cranberries 2015). Quebec province is the largest production area in Canada, followed by British Columbia, New Brunswick, Ontario, Nova Scotia, and Newfoundland (Fresh Plaza 2017).

Cranberry fruits are sour, bitter-sweet, with around 85% water content in fresh ones. Most of the production is processed (~95%), as cranberry juice and sauce. An important amount is commercialized when dried and sweetened. Due to the high acidity and tartness and low amount of sugars (compared to other fruits), cranberry juice is most of the time sweetened or mixed with other fruits to correct the acidity and sweetness. Cranberry sauce is traditional for English Christmas and Thanksgiving (in the United States and Canada), served with roast turkey. It is also used in bakery and as ingredient in different alcoholic cocktails.

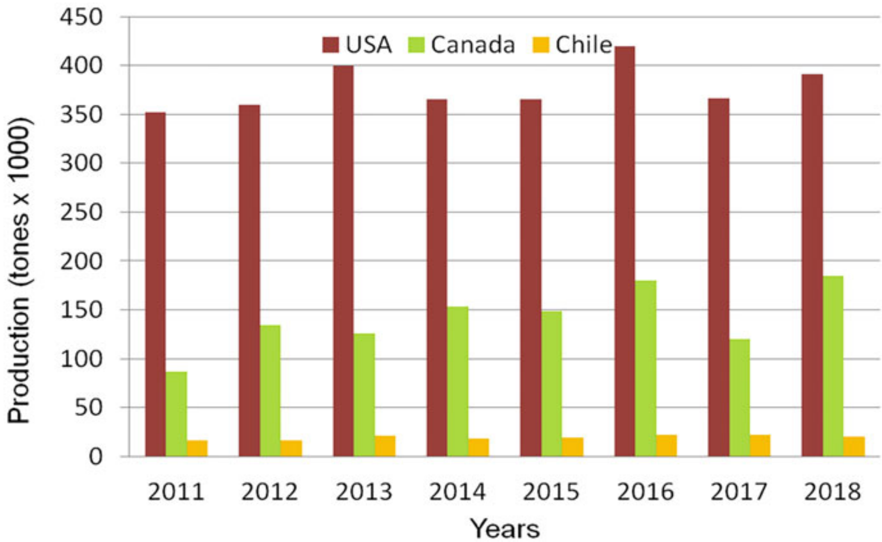

Fig. 25.2 Global cranberry production ($t \times 1000$). (Source: The Cranberry Institute 2018)

25.1.4 Botanical and Chemical Description

Vaccinium oxycoccos, known as common cranberry, small cranberry, or European cranberry, grows in cool temperate areas of Northern Hemisphere (north of Europe, but may be found also in north of Asia and some parts of northern Canada).

European cranberry may be found in wider areas than American cranberry. It occurs in forest areas in Europe, Asia, and North America. We can find this type of cranberry up to the Arctic Circle, and down to Italy and Spain. Eastern Europe, until Siberia, and the Far East are also areas where this type of cranberry grows. European cranberry is an evergreen shrub with creeping stems, growing on peat, in floody sites with very high water content. The horizontal stems, usually 30–50 cm long, have ovate leaves (8–16 mm long and 3–6 mm wide). The flowers bloom in inflorescences (two to six flowers) at the tips of shoots. Flowering period starts in May, berries are formed until August, the ripening process goes through September, and can persist on plants under the snow until spring. Fruit color passes several stages, including green, white, pink, red, and dark red (Hancock et al. 2003). The process of fruit maturation, from blooming to being ripe, takes between 60 and 120 days, depending on the climatic conditions (Česonienė et al. 2006, 2013; Brown et al. 2012). Fruits have acidic flavor, and a round, oval, or cylindrical shape (Česonienė et al. 2006, 2013). Due to the fact that it grows in northern climate, where the temperature is low, the small cranberry (European cranberry) is more resistant to cold than the large cranberry, the fruits resisting until winter time.

Different studies have determined the chemical composition of European cranberry (Jensen et al. 2002; Brown et al. 2012), and very high amounts of vitamin C (ascorbic acid) were quantified in *V. oxycoccos* compared to other species (Brown et al. 2012) and also highest amounts of citric acid (Jensen et al. 2002). The fruits of *V. oxycoccos* are darker in color, and the amount of anthocyanidins in juice was higher compared to *V. macrocarpon* juice. Also, higher soluble solids and titratable acidity were quantified in European cranberry (*V. oxycoccos*) juice.

A study made on different wild and cultivated leaves and fruits of blueberries and cranberries from Latvia (Karlsons et al. 2018) evidenced a high amount of Na, Ca, Fe, Mn, and Zn in leaf of *Vaccinium oxycoccos*, and high amounts of N, P, K, Ca, Mg, Fe, and Mn in fruits of the same berry, compared to *V. macrocarpum*, *V. myrtillus*, and *V. corymbosum*.

Vaccinium microcarpum (small cranberry) is a perennial dwarf shrub. Small in height (5 cm), it possesses creeping shoots up to 30 cm long and is finely haired. Corolla flowers are wheel-shaped, 4-5-lobate, pink-red, and approximately 4 mm broad. They flower solitary on terminate branches, having a long, erect stalk. Leaves are alternate, blade triangularly ovate, shiny dark green on top, and light-colored underside. The berries (fruits) are ovoid-spherical, up to 8 mm long (very small), dark red, and strongly acidic; the sweet taste (sugar accumulation) is more intense after frost. Their optimum habitat is on swamps and bogs. The plant grows in cold climate, where other species do not resist (northern Finland, for example). It is almost unknown and rarely studied, due to the small size of the berry and the fact that ripened fruits are available only after winter comes and in very small quantities. It is entirely wild; the cultivation of domestic varieties has still no success (Nature Gate 2020). Due to the fact that the fruits are very small, growing in Arctic climates, to the best of our knowledge, no studies of the chemical composition of *V. microcarpum* are available. Few studies talking about *V. microcarpum* (Kardell 1986; Jacquemart 1997; Nagy et al. 2017) talk about the botany, growing surfaces, and production.

Vaccinium macrocarpon is a perennial shrub with horizontal stems up to 2 m long. The stem shoots may reach 15 cm in length and here flowers and fruits are produced. Many of these shoots form on the ground a dense cover, each of them having very short internodes, where numerous buds are formed. Color of flowers is pale pink or white, grown in racemes of two to seven flowers (Brown and McNail 2006), flowering period being June–July. Pollination is made by bees and bumblebees (Kevan et al. 1983), which may be rent by cranberry farmers in order to increase the fruit number per fruiting stem. Fruit shape is of different types, from round to egg-shaped, depending on the cultivar. Also, color of the fruit depends on the cultivar, being red to dark purple; the fruits ripen from September, throughout October.

The main sugars in American cranberry are glucose, fructose, and sucrose (Oszmiański et al. 2018). Average amount of total sugars in different cranberry cultivars at commercial maturity stage was high, up to 40.9% (Oszmiański et al. 2018). The vitamin C content of *V. macrocarpon* (different cultivars) was reported in different amounts (13.7–28.5 mg/100 g; Dorofejeva et al. 2011; Schmid 1977; Viskelis et al. 2009). Organic acids were determined by Jensen et al. (2002), from different varieties of *Vaccinium* species and *Vaccinium macrocarpon* from the

Fig. 25.3 Lingonberry (*Vaccinium vitis-idaea)* from Apuseni Mountains (Romania). (Original photo: Mihai Grama)

United States, Holland, and Czech Republic. High amounts of quinic, malic, and citric acids were quantified in samples from Europe (Czech Republic), while quinic acid was quantified in higher amounts in samples from the USA, 1.14–1.18%, compared to 0.61–0.89% in samples from Holland and Czech Republic (Jensen et al. 2002).

Vaccinium erythrocarpum (southern mountain cranberry) is a foliated shrub, up to 2 m high. The leaves are bristly serrate and reticulate, thin, lanceolate (7 cm long and 3.5 cm wide), pale green on upper surface to gray-white on lower surface. It has greenish-yellow to gray-green twigs, which are striate-rugose, four-angled, and divergently branched. The flowers are hermaphrodite, pink or white in color, flowering in June–July. Berries are globulose, red to purple-black, 5–9 cm in diameter, pleasantly acid to sweet, ripening period is optimal in August–September (Uttal 1987). Distribution of the plant is discontinuous, being present in southern United States and also in eastern Asia. No studies regarding the chemical composition of *Vaccinium erythrocarpum* are available in the literature.

Vaccinium vitis-idaea, popularly named lingonberry, mountain cranberry, bearberry, foxberry, and lowbush cranberry, is native to northern parts of Europe, Russia, and Northern America; it is a wild plant, and their fruits are similar both in composition and in properties to other fruits from the genus *Vaccinium* (cranberries; Ek et al. 2006; Cătunescu et al. 2019). Although, *Vaccinium vitis-idaea* is taxonomically more closer to *Vaccinium myrtillus* L. than to other cranberry species (in Romania being found together in the same growing area; Fig. 25.3), their uses and composition are similar to other cranberry fruits (Brown et al. 2012). The plant spreads by underground stems, up to 40 cm long. Leaves are oval with slightly wavy margin, growing alternately on the stem. Flowers are white or pale pink, resembling with a bell. Lingonberry fruits are red, spherical, up to 10 mm in diameter, tartaric-acidic taste, sugars being accumulated in late autumn or early winter.

Lingonberry fruits (Fig. 25.4) contain high amounts of organic acids, vitamin C, β-carotene, and B group vitamins and also different minerals. They are widely used in different forms in human diet and also for their bioactive properties as natural

Fig. 25.4 Fruits of mountain cranberry (*Vaccinium vitis-idaea*). (Original photo: Mihai Grama and Otilia Bobis)

solutions for urinary tract diseases (Hisano et al. 2012; Davidson et al. 2014; Kirmusaoğlu 2018; Kontiokary et al. 2001; Aboderim et al. 2009), for controlling type 2 diabetes (Eid et al. 2010, 2014a, b; Rocha et al. 2019), and for their antibacterial properties (Ho et al. 2001; Diaconeasa et al. 2014; Cătunescu et al. 2019; Tsemenko 2018). Analysis of the hydrophilic fraction of different cranberry juices, including *Vaccinium vitis-idaea*, shows very high amounts of quinic and citric acids (Jensen et al. 2002).

Studying the content of fatty acid and phytosterol content of some Romanian berry pomace extracts, Dulf et al. (2012) found higher amounts of sterols in lingonberry (cowberry) pomace extract (168.21 ± 8.26 mg/100 g of lipids), with stigmasta-7,24(24^1)-dien-3β-ol, 24-methylenecycloartanol, and citrostadienol as the main sterols.

General chemical composition of cranberries includes: simple sugars, vitamins, minerals, organic acids, and small amounts of proteins and lipids, as given in Table 25.2.

25.2 Antioxidant Properties of Fruit, Juice, and Pomace

Cranberries are used as fresh fruits and are also processed in syrups, dried raisin-like product, jams, and sauces. All products have high nutritional value, due to the equilibrate chemical composition (relatively low sugar content compared to other fruits), high amount of vitamins and organic acids, and, not lately, very high amounts of phytochemicals from the class of flavonoids and anthocyanins (Schmid 1977; Viskelis et al. 2009; Dorofejeva et al. 2011; Brown et al. 2012; Oszmiański et al. 2018; Karlsons et al. 2018).

Antioxidants are chemical substances that may prevent or slower the damaged cell growth, caused by the presence of free radicals. Antioxidants are also called

Table 25.2 General chemical composition of cranberry fruits

Constituent	Quantity
Water content (%)	88.00
Reducing sugars (%)	4.20
Non-reducing sugars	0.11
Acids (as citric acid) (%)	2.40
Pectin (%)	1.20
Lipids (etheric extract) (%)	0.40
Proteins (%)	0.20
Ash (%)	0.25
Potassium (K) (mg)	53.0
Sodium (Na) (mg)	2.0
Calcium (Ca) (mg)	13.0
Phosphorus (P) (mg)	8.0
Magnesium (Mg) (mg)	5.5
Iron (Fe) (mg)	0.4
Vitamin A	40 IU
Vitamin C (mg)	7.5–10.5
Thiamin (vitamin B1) (μg)	13.5
Riboflavin (vitamin B2) (μg)	3.0
Nicotinic acid (vitamin B3) (μg)	33.0
Pantothenic acid (vitamin B5) (μg)	25.0
Pyridoxine (vitamin B6) (μg)	10.0
Biotin (vitamin B7) (μg)	Traces
Energy	109.2 kJ

Adapted from Eck (1990) and Hancock (2003)

"free-radical scavengers." Free radicals are produced by the cells of the human body, as they process foods or react to various environmental contaminants. Free radicals are also called reactive oxygen species (ROS). Antioxidants may be natural or artificial. Plants and plant-based foods contain high amounts of natural antioxidants.

Oxidative stress is defined as an imbalance between free radicals and the level of antioxidants in human body. If this imbalance is maintained for long periods of time, different illnesses may appear. Nowadays, it is confirmed that diabetes, atherosclerosis, high blood pressure, heart disease, different neurodegenerative diseases, and cancer are related to oxidative stress and ROS imbalance.

Different spectrophotometric methods are used in the evaluation of the antioxidant activity (Pisoschi and Negulescu 2011): 2,2-diphenyl-1-picrylhydrazyl method (DPPH; Brand-Williams et al. 1995); 2,2′-azino-bis(3-ethylbenzthiazoline-6-sulfonic acid) method (ABTS; Re et al. 1999); ferric reducing antioxidant power method (FRAP; Benzie and Strain 1999); Oxygen radical absorption capacity assay (ORAC; Ou et al. 2001); lipid peroxidation inhibition assay (Zhang et al. 2006); cupric reducing antioxidant power assay (CUPRAC; Apak et al. 2004).

A comprehensive food database of 3100 typical foods, beverages, traditional medicinal plants, herbs and spices, and dietary supplements was published in 2010

(Carlsen et al. 2010) and cranberry is mentioned as a fruit with important antioxidant activity. Cranberry fruits have a special phenolic composition, including three important classes of flavonoids (flavonols, anthocyanins, and proanthocyanidins), catechins, and phenolic acids (Silva Caldas et al. 2018), which prove to be responsible for the antioxidant activity.

Brown et al. (2012) compared three *Vaccinium* species (*V. oxycoccos* L., *V. vitis-idaea* L, and *V. macrocarpon* Ait.) and observed a strong negative correlation between the anthocyanin content and the antioxidant potential using DPPH method. But the antioxidant potential was correlated with vitamin C content and also with serotonin content (Brown et al. 2012): the higher the vitamin C and serotonin content, the lower the amount of cranberry needed for reducing with 50% the DPPH radical.

Viskelis et al. (2009) studied the antioxidant activity of cranberry fruits and press cake ethanolic extracts, and found no significant differences between the two matrices (76.08% for berry extracts and 71.26% for press cake extract), but a positive correlation between phenolic content and antioxidant activity was found in this study: all analyzed cultivars present higher amounts of anthocyanins and total phenolics in press cake, compared to fruit extracts (Viskelis et al. 2009). Also, other studies (Seeram 2008; Zheng and Wang 2003) described the same correlation.

The exact mechanism by which cranberry polyphenols promote their antioxidant activity has not yet been fully elucidated, only the observations of positive action is noticed. The observation made in these studies is that cranberry polyphenols act in the same way as other fruit polyphenols. Two mechanisms of action have been described in the literature: a direct mechanism, where the radical superoxide and other reactive oxygen species of the organism are eliminated by the polyphenols; and an indirect mechanism, where the antioxidants (polyphenols) stimulate endogenous antioxidant defense, stimulating the transcription factor NF-E2 responsible for regulating the expression of the enzymes from the antioxidant substance, enzymes like catalase and glutathione (Milbury et al. 2010; Joseph et al. 2016).

The study of Joseph et al. (2016) demonstrate that cranberry juice intake (with determined polyphenolic content) induces high increase in plasma concentration after 4 h from juice ingestion. The rapid removal of these compounds from the organism suggests that the ingested concentration is insufficient to amend the cellular redox state through free radical neutralization (corresponding to the direct mechanism), but could affect the gene expression (corresponding to the indirect mechanism), and could potentially increase the synthesis of the mentioned antioxidant enzymes (catalase and glutathione).

25.3 Characterization of the Chemical Compounds Responsible for Antioxidant Proprieties and the Pathways Involved in the Biological Activities

Cranberries belong to a type of beneficial fruits, from nutritional point of view and biological activities, because they have low carbohydrate content compared to other fruits, and a very high content of vitamins, minerals, and phenolic compounds (phenolic acids, flavonoids, anthocyanins, proanthocyanidins, and terpenes), substances that confer high antioxidant activity (Ho et al. 1999; Brown et al. 2012; Diaconeasa et al. 2014; Zhao et al. 2018; Cătunescu et al. 2019).

The bioactive properties of lingonberry are due to their chemical composition, high in flavonoids and vitamins. These compounds, individually or in combination, are responsible for the health benefits registered when different berries are consumed.

As was mentioned before, cranberries (all types, species, and cultivars) are characterized by a wide range of phenolics, including phenolic acids, flavonols, catechins, proanthocyanidins, anthocyanins, and terpenoids (Table 25.3).

Generally, the methods used for antioxidant identification and quantification are chromatographic ones, mainly liquid chromatography, coupled with mass spectrometry detection (for example, high performance liquid chromatography–mass spectrometry [HPLC-MS]), but also gas chromatography (GC), for phytosterol determination.

Fatty acids and phytosterols are also bioactive compounds, found in cranberries. The lipidic profile depends on their taxonomy, and the determination method suitable for these classes of compounds is gas chromatography. High amounts of C18 unsaturated fatty acids and phytosterols have been identified using gas chromatography–mass spectrometry (GC-MS) technique from different cranberry cultivars (Lyutikova and Turov 2011; Dulf et al. 2012; Klavins et al. 2016).

Another phytochemical with great importance as antioxidant is vitamin C. Different studies show that the accumulation of ascorbic acid in cranberries is related to the cultivar, showing that wild cranberry contain higher amounts of ascorbic acid (31 mg/100 g) compared to cultivated breeds (28.6 mg/100 g; Tikuma et al. 2014), which also increases during ripening (Viskelis et al. 2009).

Jensen et al. (2002), using HPLC-US, HPLC-MS, and HPLC-NMR (nuclear magnetic resonance), quantified the organic acids and some phenolic acids in the juice of cranberry, lingonberry, and blueberry fruits. The highest amounts of hydrophilic carboxylic acids were determined in cranberries (2.67–3.57%) and lingonberries (2.27–3.05%).

Using LCT time-of-flight (TOF) mass spectrometer and liquid chromatography–mass spectrometry (LC-MS/MS), Ek et al. (2006) tentatively identified 28 phenolic compounds in *Vaccinium vitis-idaea*, and detailed identification was made using ^{1}H NMR spectroscopy. Eight of the compounds were reported for the first time in lingonberry, and two of the compounds, flavonol acylglycosides quercetin-3-*O*-[4″-(3-hydroxy-3-methylglutaroyl)]-α-rhamnose and kaempferol-3-*O*-

Table 25.3 Polyphenolic and anthocyanidin profile of different *Vaccinium* leaves and fruits

Vaccinium species	Bioactive compound	References
Vaccinium oxycoccos	Benzoic acid, *p*-coumaric acid, chlorogenic acid, caffeic acid, ferulic acid, cyanidin-3 galactoside, quercetin, myricetin, epicatechin, isorhamnetin, cyanidin-3-glucoside, cyanidin-3-arabinoside, peonidin-3-galactoside, peonidin-3-glucoside, peonidin- 3-arabinoside	Stobnicka and Gniewosz (2018), Ehala et al. (2005), Česoniennė et al. (2009, 2011, 2015), Häkkinen et al. (1999), and Gniewosz and Stobnicka (2018)
Vaccinium macrocarpon	*p*-Coumaroyl hexose, caffeoyl dihexoside, delfinidyn-3-*O*-glucoside, cyanidin-3-galactoside, chlorogenic acid, catechin, cyanidin-3-*O*-glucoside, cyanidin-3-*O*-arabinoside, peonidin-3-*O*-galactoside, peonidin-3-*O*-glucoside, peonidin-3-arabinoside, myricetin-3-*O*-pentoside, myricetin-3-*O*-glucoside, myricetin-3-*O*-galactoside, quercetin-3-*O*-galactoside, betulinic acid, oleanolic acid, ursolic acid	Cunningham et al. (2004), Harnley et al. (2006), Zheng and Wang (2003), Wu and Prior (2005), Zuo et al. (2002), Chen et al. (2001), Zhang and Zuo (2004), Gu et al. (2004), and Muller et al. (2007)
Vaccinium vitis-idaea	*Leaves*: Proanthocyanidin dimer type A1, trans-chlorogenic acid, caffeic acid, caffeoylquinic acid, *p*-coumaric acid, quercetin-3-*O*-β-galactoside, quercetin-3-*O*-glucoside, rutin, quercetin-3-*O*-α-arabinoside, quercitrin, quercetin, quercetin-3-*O*-(4″-HMG)-α-rhamnoside, kaempferol-(HGM)-rhamnoside *Fruits*: Myricetin-galactoside, quercetin-rutinoside, myricetin-arabinoside, myricetin-glucoside, quercetin-galactoside, quercetin-acetyl-glucoside, quercetin-glucoside, quercetin-rhamnoside, cyanidin-3-*O*-galactoside, petunidin-3-*O*-galactoside, cyanidin-3-*O*-glucoside, cyanidin-3-*O*-arabinoside, peonidin-3-*O*-galactoside, peonidin-3-*O*-glucoside, malvidin-3-*O*-arabinoside	Hokkanen et al. (2009), Diaconeasa et al. (2014), Ho et al. (2001), Cătunescu et al. (2019), Ek et al. (2006), Bujor et al. (2018), and Viskelis et al. (2009)

[4″-(3-hydroxy-3-methylglutaroyl)]-α-rhamnose, were reported entirely for the first time.

Back in 2009, Pappas and Schaich published a comprehensive review on the phytochemicals of cranberry and their potential health effects. At the time it was the most complete review, stating that over 150 individual phytochemicals were identified and studied in cranberries. The dominant class was flavonoids:

anthocyanins, responsible for the red color of the fruit; flavonols, secondary yellowish pigments; and proanthocyanidins, with high biological activity for the urinary tract infections. Other classes include catechins, organic acids and resveratrol (giving the sour, astringent flavor), different terpenes giving the aroma of the fruits, and pectins, having role in the gelification of the cooked fruits.

Comparing three *Vaccinium* species (*Vaccinium macrocarpon*, *V. oxycoccos*, and *V. vitis-idaea*), Brown et al. (2012) demonstrated that *V. vitis-idaea* contains the highest amount of cyanidin-3-*O*-galactoside, cyanidin-3-*O*-arabinoside, and also the highest amount of serotonin, from the analyzed species. The studies were confirmed also by different other authors (Diaconeasa et al. 2014; Cătunescu et al. 2019).

Using cranberry pomace, provided from a commercial cranberry juice manufacturer and flash chromatography with Sorbent SP207-05 Sepabeads resin, Vasantha Rupasinghe et al. (2019) fractionated the extract obtained from cranberry pomace. Further on, an ultrahigh performance liquid chromatography (UHPLC) mass spectrometry (MS) detection was used for metabolite characterization. Chlorogenic, caffeic, ferulic, and isoferulic acids, catechin, epicatechin, epigallocatechin, epigallocatechin gallate, epicatechin gallate, quercetin, quercetin rutinoside, quercetin galactoside, quercetin glucoside, quercetin arabinoside, quercetin rhamnoside, phloretin, phloridzin, and cyanidin-3-*O*-glucoside were identified and quantified in the extracts. Even if the analysis methods evolved, similar compounds are identified in cranberry, fruits, juice, or pomace.

25.4 Health Benefits

Cranberries are very rich in phytochemicals that act like antioxidants when consumed as fresh fruits or juice. These compounds are concentrated in the skin and are diluted in the juice. The most important antioxidants responsible for their health benefits are flavonoids, ursolic acid, and A-type proanthocyanidins. Numerous original research studies and review articles discussing the nutritional and biological properties of cranberries were published in food and medical journals (Reference list). The studies describe chemical composition determination, in vitro studies of biological activities, and animal and human clinical and epidemiological studies. Some key points may be evidenced from these studies (Fig. 25.5):

- Human studies are very much focused on the effect on urinary tract health, but also on cardiovascular disease, cancer prevention, glycemic response, oral health, and against *Helicobacter pylori* bacteria.
- The mentioned studies have explored the role of the major phytochemicals present in cranberry and their activities in vitro or in vivo on animals and human studies.
- Research on some specific phytochemicals that may be responsible for the bioactivity that every study was demonstrating. Much attention was given to proanthocyanidins (especially type A), evaluating its role in adhesion of different bacteria to cells, causing gastrointestinal and urinary diseases.

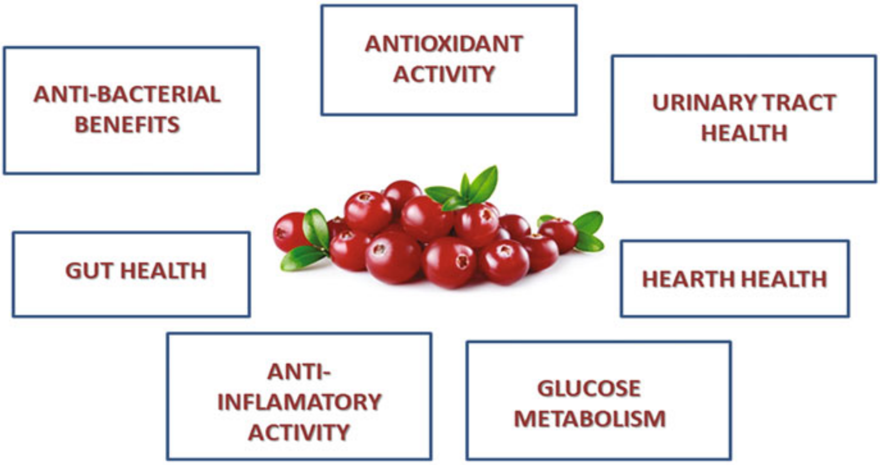

Fig. 25.5 Biological activities of cranberry

There is still a long road to go until the optimal form, amount, and frequency of consumption will be established for every disease, in order to reduce health risks, or to promote good health, because it is known that high amounts of cranberry consumption, or for long periods of time, may have adverse effects (thrombocytopenia, elevate oxalate in the urine, and nephrolithiasis; McHarg et al. 2003; Gettman et al. 2005; Royer et al. 2010).

25.4.1 Urinary Tract Health

Urinary tract infection (UTI) is among the most common bacterial infectious diseases in humans; more than 50% of women and 5% of men suffer from this disease at least one time in their life. The primary causing agent is uropathogenic *Escherichia coli*, which may develop antibiotic resistance to classical treatment (Aboderin et al. 2009; Kazemnia et al. 2014). Generally, cranberries (*Vaccinium erythrocarpum*, *Vaccinium macrocarpon*, *Vaccinium microcarpum*, and *Vaccinium oxycoccos*) are recommended for urinary tract infections, as different scientific studies are thought to be able to inhibit the attachment of *Escherichia coli* to the bladder wall, reduce the bacterium in the urine, and prevent the accumulation of this bacteria in the urinary tract (Ofek et al. 1991; Avron et al. 1994; Takahashi et al. 2013; Mathison et al. 2014; Harich et al. 2017; Zhao et al. 2018; Kim et al. 2019). These activities were assigned to A-type proanthocyanidins (Howell et al. 2005), which cranberry contains, being among the few foods that contain this type of proanthocyanidins. However, there is no clear evidence that either the preparations or the cranberry juice has a quantifiable effect in reducing urinary tract infections or could be used for prophylactic purposes.

Different cranberry-based products were assessed for their efficacy and safety for preventing recurrent UTI in humans (Parshottam et al. 2019; Haiyan et al. 2019).

One product containing two strains of *Lactobacilli* plus cranberry extract (Bio-Kult Pro-Cyan) was used in a randomized, double-blind, placebo-controlled pilot study. Subjects (premenopausal women) received BKPro-Cyan or placebo twice-daily for 26 weeks. From the 115 subjects screened, 90 were enrolled and 81 completed the study. After 26 weeks, a significantly lower number of women experienced recurrent UTIs with BKPro-Cyan compared to placebo (9.1% vs. 33.3%). BKPro-Cyan was safe and effective for preventing recurrent UTI in premenopausal adult women (Parshottam et al. 2019).

The activity against type 1 and P-type uropathogenic *E. coli* after consumption of cranberry +health™ cranberry supplement (cranberry chew) was evaluated in a randomized, double-blind, placebo-controlled, crossover design pilot trial ($n = 20$ subjects). Urinary anti-adhesion activity against P-type *E. coli* after consumption of the cranberry chew was significantly greater ($p < 0.05$) compared to placebo chew at all time points (Haiyan et al. 2019).

A recent study (Bruyere et al. 2020) compared the efficacy of one product containing cranberry and propolis to a placebo group, for reducing frequency of cystitis in women with recurrent acute cystitis. The subjects were 85 women aged >18 years with at least 4 episodes of cystitis in the previous 12 months (42 in experimental group and 43 in placebo group). The mean age was 53 ± 18 years, with 6.2 ± 3.6 cystitis episodes in the previous year, with no differences between the two groups. Tolerance to the treatments was good and comparable in both groups. As results, the mean number of infections was lower in the propolis + cranberry group (respectively, 2.3 ± 1.8 vs. 3.1 ± 1.8). The total number of cystitis episodes in the first 3 months was lower in the experimental group (0.7 ± 1.1 vs. 1.3 ± 1.1). The mean time to onset of the first urinary tract infection (UTI) was also significantly longer in the propolis + cranberry group (69.9 ± 45.8 days vs. 43.3 ± 45.9). The study demonstrates for the first time that propolis may have a synergistic effect on cranberry supplementation, which significantly reduces the incidence of UTIs during the first 3 months and delays the onset of a new episode of cystitis.

Chronic kidney disease is described as a global health problem. When the disease reaches chronicization, it means that it is associated with a number of complications such as malnutrition, decreased quality of life, and reduced life expectancy (Stenvinkel 2010; Webster et al. 2017; de Almeida Alvarenga et al. 2019).

25.4.2 Glucose Metabolism

Diabetes mellitus is a chronic metabolic disease characterized by high levels of sugars in the blood, resulting from defects in insulin secretion and insulin action. Type 2 diabetes is the most prevalent form of all cases of diabetes, which numbers more than 450 million adults in the world, causing also other type of diseases and increasing the risk of cardiovascular diseases also.

Different studies regarding the use of cranberry in the control of diabetes were published (Wilson et al. 2008; Hoggard et al. 2013; Mirfeizi et al. 2016; Rocha et al. 2019). The benefits of cranberry in glycemic control effects were also demonstrated both in vitro and in animal studies (Anhê et al. 2013; Elks et al. 2015).

One of the last reviews (Calvano et al. 2019) summarizes and discusses the role of dietary berries (consumed fresh, frozen, or in other processed forms) on insulin resistance and biomarkers of type-2 diabetes (T2D) in human feeding. The studies report feeding trials that involve different berries taken in different forms, and consequently differences in nutritional or polyphenol composition are considered in the interpretation. Commonly consumed berries, cranberries, blueberries, raspberries, and strawberries, ameliorate postprandial hyperglycemia and hyperinsulinemia in overweight or obese adults with insulin resistance, and in adults with the metabolic syndrome (MetS). The metabolic syndrome (visceral obesity, dyslipidemia, hyperglycemia, and hypertension) has become one of the major public-health challenges worldwide. These berries, consumed either alone or in combination with other functional foods, can improve glycemic and lipid profiles, blood pressure, or surrogate markers of atherosclerosis, thus MetS. Studies specifically in people with T2D are few, and more knowledge is needed. Nevertheless, existing evidence suggests that berries have an emerging role in dietary strategies for the prevention of diabetes and its complications in adults, but must be consumed as part of a healthy and balanced diet. The lipid biomarkers used to monitor and predict cardiovascular diseases (CVD), elevated low-density lipoprotein (LDL) and reduced high-density lipoprotein (HDL) cholesterol (C), as well as high triglyceride values in humans deserve special attention in their predictive abilities. Using different berries in the daily diet, scientific studies have been shown to lower total and LDL-C, and increase HDL-C in participants with elevated blood lipids, type-2 diabetes, or metabolic syndrome. All conclusions showed that colorful berry fruits may be included in a healthy diet for the prevention and management of CVD and other illnesses related to metabolic syndrome (Basu 2019).

25.4.3 Antibacterial Activity and Dental Care

Vaccinium vitis-idaea leaf and berries possess antiviral and anti-inflammatory properties, studied since several decades (Fokina et al. 1993; Tunon et al. 1995). The bioactive compounds from the chemical composition (phenolic acids, flavonoids, anthocyanins, tannins, carotenoids) are responsible for these properties.

A study conducted in 2018 (Tsemenko 2018), using different extraction solvents on *Vacciniun vitis-idaea* leaves, showed a different antibacterial activity depending on the compounds extracted with the used solvents. The highest antibacterial activity against different bacterial strains (*Escherichia coli*, *Staphylococcus aureus*, *Proteus vulgaris*, *Pseudomonas aeruginosa*, *Candida albicans*) exhibits glycosides of phenolic compounds, followed by flavonoidic aglycones and polysaccharides from the extract.

Aqueous and methanolic extracts obtained from fresh, frozen, and dried fruits of *Vaccinium vitis-idaea* were tested in vitro on *Staphylococcus aureus* (ATCC 25923), *Escherichia coli* (ATCC 25922), and *Salmonella typhimurium* (ATCC 13076). No inhibition was present in the case of *S. aureus* and similar zone of inhibition for the other two bacterial strains (9.00–12.93 mm), regardless of the pretreatment applied on the berry (Cătunescu et al. 2019).

Tannins isolated from *V. vitis-idaea* were demonstrated to have antimicrobial activity against different periodontal pathogens. A strong antimicrobial effect of epicatechin-(4β → 8)-epicatechin-(4β → 8, 2β → *O* → 7)-catechin on *Porphyromonas gingivalis* and *Prevotella intermedia* was obtained (Ho et al. 2001). This may be useful as oral antiseptic in different formulations to prevent different periodontal diseases.

Water-soluble (Fraction I) and polyphenol-rich fractions (Fraction II) of cranberries and lingonberries significantly reduced biofilm formations by *Streptococcus mutans* MT8148R, *Streptococcus sobrinus* 6715, and *Streptococcus sanguinis* ATCC 10556 (Kobuku et al. 2019). Also, pathogenesis of early childhood caries was improved using polyphenol-rich extracts of cranberry (Philip and Walsh 2019).

25.4.4 Heart Health

Cardiovascular metabolic risk factors are decreased by using supplementation of cranberry in human diet (Pourmasoumi et al. 2019). The cardiovascular protective properties of cranberry are until now investigated in animal (Maher et al. 2000; Apostolidis et al. 2006) and human studies (Basu et al. 2011; Dohadwala et al. 2011).

Dohadwala et al. (2011) designed a study comprising of two parts: an acute pilot study, where 15 subjects with coronary artery disease (62 ± 6 years, 13% female) have participated, and a chronic randomized crossover study, where 47 participants were qualified and start cranberry beverage consumption. In the acute pilot study, a high prevalence of risk factors, including hypertension (53%), history of cigarette smoking (67%), and diabetes mellitus (33%) was registered. Also, the participants have a drug history, including lipid-lowering therapy (100%), angiotensin-converting enzyme inhibitor/angiotensin receptor blocker therapy (60%), and aspirin (100%). Significant improvements in brachial artery flow-mediated dilation 4 h after cranberry juice ingestion and in the lnPAT ratio 2 and 4 h after acute juice consumption were observed. A modest decrease in resting brachial artery blood flow was found, but no effects on hyperemic flow, baseline brachial diameter, blood pressure, or heart rate. Regarding the second part of the study, the subjects who completed the study, divided in two subgroups (placebo and cranberry juice consumers), were middle aged, predominantly white, with history of hypertension, diabetes mellitus, smoking, having lipid-lowering therapy, aspirin therapy, and being overweight, having body mass index (BMI) 30 ± 5, thus concluding with high prevalence of risk factors. After 4 weeks of juice consumption, a cumulative effect on brachial artery flow-mediated dilatation was observed. No effects on blood pressure, baseline or hyperemic flow, or nitroglycerin-mediated dilatation were found. Compared to placebo group, the experimental group presented a favorable effect on arterial stiffness. Carotid-femoral pulse wave velocity decreased by 6% after cranberry juice consumption and increased slowly after placebo substance ingestion.

In order to draw a good conclusion, other studies must be undertaken, especially on humans. Numerous studies demonstrate that cranberry may have beneficial effects on reducing systolic blood pressure (Basu et al. 2011; Flammer et al. 2013; Ruel et al. 2013) and body mass index (Novotny et al. 2015; Zare et al. 2018). This systolic blood pressure-lowering effect is robust in people >50 years old (Basu et al. 2011; Zare et al. 2018). Also, the results showed that cranberry might be effective in terms of increasing HDL levels in adults <50 years old. Studies indicate that quercetin may be responsible for the blood pressure-lowering effect through reducing oxidative stress and improving endothelium vasodilatation. Cranberry is a fruit with high content of quercetin and its glycosides; being a safe and popular fruit, it can be considered an adjuvant along with current pharmacological treatment used in cardiovascular diseases.

The only problem that patients with CVD have to take into consideration is the possible interaction between cranberry and warfarin. People who use anticoagulant agents have to be cautious, because of the possible interaction between the two (Aston et al. 2006; Mohammed et al. 2008), but on this problem, again, the opinions are divided (Ansell et al. 2009; Zirkia et al. 2010).

25.4.5 Anticancer Activity

Numerous studies have shown that cranberry fruits and their phytochemicals may exert anticancer properties. First in vitro study, reporting the anticancer activity of *Vaccinium* fruits, was published in 1996 (Bomser et al. 1996). The study demonstrates that the extracts of different berries inhibit ornithine decarboxylase expression and induce the xenobiotic detoxification of quinine reductase in vitro. Later, Ferguson et al. (2004) performed a study demonstrating that an extract of cranberry press cake inhibited the proliferation of MCF-7 and MDA-MAB-435 breast cancer cells.

All bioactive substances after human ingestion are excreted through urine. Starting from this, an inhibitory effect of the phytochemicals on bladder carcinogenesis is very plausible. In an in vitro study (Prasain et al. 2016), different cranberry derived flavonoids were evaluated using three human bladder tumor cell lines (RT4, SCABER, and SW-780) and a non-tumorigenic human uroepithelial cell (SV-HUC). Quercetin, isorhamnetin, myricetin, quercetin-3-*O*-glucoside, quercetin-3-*O*-galactoside, quercetin-3-*O*-rhamnoside, cyanidin-3-*O*-galactoside, cyanidin-3-*O*-glucoside, and peonidin-3-*O*-glucoside were the tested compounds.

Quercetin 3-*O*-glucoside, isorhamnetin, quercetin, and myricetin showed moderately IC50 activity, values ranging from 8.7 to 92.4 μM in bladder cancer cells. The antiproliferative activity of quercetin with its glycoside analogs was compared. Compared to the aglycone quercetin, glycoside analogs of quercetin showed no growth inhibitory activity, including quercetin-3-*O*-galactoside. Quercetin-3-*O*-rhamnoside showed weaker activity than quercetin-3-*O*-glucoside. These indicate that the nature and number of sugar residues play important role in antiproliferative activities. Isorhamnetin showed a slightly increased anticancer activity, compared to quercetin. Concluding, quercetin-3-*O*-glucoside, isorhamnetin, myricetin, and quercetin presented dose-dependent inhibitory effects against bladder cancer cells, and may be responsible for the cancer preventive activity of cranberry, demonstrated previously in a rat model of chemical-induced bladder tumor (Prasain et al. 2008).

Oral cancer represents a global pandemic. Chlorhexidine is one of the drugs used to treat this type of cancer. In a recent study (Khairnar et al. 2018), chlorhexidine and cranberry extract were used in vitro to evaluate their anticancer properties. AW13516 squamous cell carcinoma of tongue and KB nasopharyngeal carcinoma were analyzed using Sulforhodamine B assay. Thus, 80 μg/mL cranberries' extract shows 70.6% growth inhibition against KB cell line, but no effect upon AW13516 cell line; meanwhile chlorhexidine exhibits very high growth inhibition on both cell lines.

A recent study (Bystrom et al. 2019) evaluated cranberry proanthocyanidin A-type on leukemia cell lines, primary acute myelogenous leukemia cells, and normal $CD34^+$ cord blood cells. The in vitro study indicated potent and specific antileukemia activities. Additionally, this activity of A-type proanthocyanidins extended to malignant progenitor and stem cell populations, sparing their normal counterparts. The conclusion of the study was that A-type proanthocyanidins could be used to improve treatments for acute myelogenous leukemia by targeting leukemia stem cells through a novel pathway.

25.5 Conclusion

Hundreds of research and review studies are published all over the world, in nutritional and medical databases, regarding analytical, chemical, nutritional, and phytomedical uses of cranberry. This research pathway remains a priority for scientists all over the world, who need to understand the impact of dose and duration of natural treatment to be effective in different metabolic diseases (urinary tract diseases, type 2 diabetes, heart diseases, inflammatory processes, or different bacterial diseases). All these problems are related to the oxidative processes existing in human body. For this reason, investigating the natural antioxidants has been and will be topical. Studying different *Vaccinium* species is a great opportunity for pharmaceutical industry, to develop alternative approaches to classical treatments of above mentioned diseases.

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Apple

26

Rafiya Mushtaq, Ab Waheed Wani, and Gulzar Ahmad Nayik

Abstract

Fruits are the most important source of antioxidants and for the same reason fruit consumption has increased nationally and internationally. Among fruits, apple has got maximum scientific attention because of its high nutraceutical values. It belongs to a *rosaceous* family in the genus *Malus*. It is the most widely cultivated fruit crop in temperate regions of the world and has been cultivated in Europe and Asia since antiquity. The fruit is rich in fibers, with no cholesterol, and also contains appreciable amounts of various naturally occurring phytochemicals like phenols, flavonoids, and other antioxidants that impart numerous health benefits. Apple contains different groups of polyphenols, such as (+)-catechin, (−)-epicatechin, quercetin (flavonols), phloridzin (dihydrochalcone glycosides), chlorogenic acid (phenolic acids), cyanidin-3-*O*-galactoside (anthocyanins), cyaniding (anthocyanidins), and hydroxycinnamates. The range of these polyphenols, however, varies depending on various factors like cultivar, cultivation methods, climatic conditions, and others. There is a wide range in concentration of these polyphenols even within the fruit. This chapter, therefore, summarizes the information on the presence of various polyphenolics in apple fruit, peels, seeds, juice, and other apple products and their health-related properties.

Keywords

Apple · Polyphenols · Antioxidant activity · Health benefits · Peel · Seed

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26.1 Introduction

Apple, the premier fruit, belongs to a *rosaceous* family in the genus *Malus*. It is the most widely cultivated fruit crop in temperate regions of the world and has been cultivated in Europe and Asia since antiquity. Apple trees are low spreading with a round canopy having adventitious roots. Leaves are simple with actinomorphic flowers and semi-inferior ovary. The fruit is pome with fleshy thalamus as an edible part. Apple fruits are rich in dietary fiber; however, they show low-calorie content, and also contain no saturated fats or cholesterol. Apples are also rich in phytonutrients, antioxidants, flavonoids, and polyphenolics. Important polyphenols present in apples are epicatechin, catechin, quercetin, and rutin. Additionally, they are also good in tartaric acid that gives tart flavor to them. Carbohydrates present in apple comprise sugars, starch, dextrin, hemicellulose, cellulose, and other pectin substances. It is also found to contain appreciable amounts of sorbitol and other sugars. Half of the apples produced all over the world are consumed as fresh and the other half is processed into various apple products like juice, sauce, and jam.

26.1.1 History

The native species of genus *Malus* originated from the region of Asia Minor, Central Asia, the Caucasus, China, Pakistan, and Himalayan India. The opening of trade routes from China to the Middle East and Europe via Central Asia—"The Old Silk Road"—played a key role in the evolution and in spreading of cultivated apple (Boudichevskaja 2009; Forsline et al. 2003). As reported by Boudichevskaja (2009) in Ancient Greece and Persia, certain techniques (pruning, storage, grafting, precise rootstock usage, and selection of distinctive apple clones) of apple cultivation were already used and 20 varieties of cultivated apples in several regions were described. Janick (2005) mentioned that Persia was patently the source of apple and other numerous fruits originated from Central Asia. Wild apple fruits were cultivated and frequently spread throughout Europe and Mideast, which led to the cultivation of thousands of unique and new varieties (Janick 2005). Apples have been widely planted all over Europe and consumed as a raw fruit, fermented juice or cider, vinegar, applejack, as well as cooked and mixed with sugar and sweets. In the eighteenth and nineteenth centuries, more than one hundred apple cultivars were described and categorized based on their final application and availability (Harris et al. 2002). Until the introduction of *M.* × *domestica* in the late nineteenth century, the Chinese pear leaf crabapple *Malus asiatica* Nakai was the major cultivated species in southern and eastern Asia.

26.1.2 Production (India, World)

As an important commercial crop, apple is cultivated in all the temperate regions of the world. Indeed, apple is the most widely spread important commercial crop of temperate regions under high altitudes (Forsline et al. 2003). The world production of apples is 83.13 million MT (FAOSTAT 2019). China leads in production and export of apples, by producing around 41% of the world's apples followed by the USA. Chile is the second-largest exporter of apples in the world. India ranks fifth in apple production with a total production of 2.26 million MT (FAOSTAT 2019). In the United States, leading apple-producing states are Washington and Michigan. In Europe, major apple producers are Italy, France, and Germany. The other countries which also contribute to apple production are Iran, Turkey, USSR, etc. In India, apple production is concentrated in the north-western Himalayan regions that comprise Jammu and Kashmir, Himachal Pradesh, and Uttarakhand and to some extent in the north-eastern states like Arunachal Pradesh, Sikkim, Meghalaya, Mizoram, Nagaland, and Manipur. In Jammu and Kashmir, it is grown over an area of 164.74 thousand ha with a production of 1882.31 thousand MT (Anonymous 2019). J&K is the leading producer of apple in the India contributing around 60% of total production. Currently, some cultivars, such as Delicious and Golden Delicious, are grown almost in all apple-producing countries. In major countries, which produce apple, breeding projects are producing new cultivars with enhanced quality and other features, for instance, disease resistance (Jones and Aldwinkle 1990).

26.1.3 Botanical Description

Apples (genus *Malus*) belong to the *Rosaceae* family, in one of its subfamilies Pomideae having basic chromosome number 17. The genus *Malus* has approximately 30 species (Rehder 1954). *Malus pumila* Mill., formerly *Malus communis*, is considered as the parent of most of the cultivated apples. Earlier research studies showed that *Malus sieversii* was the most important source of a gene pool of *Malus* × *domestica* (Kumar et al. 2014). However, as Cornille et al. (2014) reported, European crabapple *Malus sylvestris* has been an important secondary contributor as it is similar to domesticated apple species. *Malus sieversii* has interesting diversity for different important traits, and thus it can be used in breeding to improve and develop market-driven cultivars (Pereira-Lorenzo et al. 2009; Janick 2005). The *Malus* taxonomy is challenging as the differences between wild and cultivated species are unclear and therefore difficult to distinguish particular varieties (Harris et al. 2002). The majority of cultivated apple varieties are diploid ($2n = 34$). However, triploids ($2n = 51$) and tetraploids ($2n = 68$) also exist.

26.2 Antioxidant Properties

The substances or compounds which prevent or detain the oxidation of oxidizable substrates by squishing or stabilizing free radicals are called antioxidants. Free radicals are reactive chemical species that are formed during the oxygen transfiguration and could damage cellular machinery. However, their harm is mitigated by many naturally occurring compounds like phytochemicals, nutraceuticals, or functional compounds due to their antioxidant potential. Phytochemicals present in various fruits, vegetables, cereals, and herbs impart protection against many chronic diseases, such as cancers and cardiovascular diseases. Polyphenols, a category of phytochemicals, manifest antioxidant activity as they scavenge free radicals, hamper lipid peroxidation by obstructing the activity of lipoxygenase enzyme (Laughton et al. 1991), and show manifold effects on cell functions like inflammatory and immune functions (Decharneux et al. 1992). The anti-hemolytic activity exhibited by polyphenols is due to their role in preventing low-density lipoprotein (LDL), oxidation by macrophages and arresting cytotoxicity of oxidized LDL on lymphoid cell lines (Negre-Salvayre and Salvayre 1992). Various polyphenols like flavonoids show antioxidant properties by affecting cellular secretory processes, capillary permeability, cell membrane receptors, and their carriers. Besides reducing the risk of coronary heart diseases (Hertog et al. 1993), it acts as a mutagenic, antiviral, antibacterial, and antifungal agent. Fruits are the most important source of antioxidants and for the same reason fruit consumption has increased nationally and internationally. Among fruits, apple has got maximum scientific attention because of its high nutraceutical values. The remarkable adage "*An apple a day keeps the doctor away*!" is often prescribed to people to stay healthy. Besides, apple fruits, such as sweet cherries, black plums, strawberries, raspberries, cranberries, oranges, red grapes, figs, and apricots, are important sources of antioxidants. Mostly the antioxidant property of fruits is associated with their polyphenolic content. Polyphenolic compounds are plant-based biologically active compounds (BAC) that strengthen the organism and prevent chronic diseases (El Gharras 2009).

A significant amount of phytochemicals is found in various fruit crops like pome fruits, stone fruits, and berries. Apple contains different groups of polyphenols, such as (+)-catechin, (−)-epicatechin, quercetin (flavonols), phloridzin (dihydrochalcone glycosides), chlorogenic acid (phenolic acids), cyanidin-3-*O*-galactoside (anthocyanins), cyaniding (anthocyanidins), and hydroxycinnamates (Cuthbertson et al. 2012). The polyphenolic content of apple (mg/fruit) varies between 19.6–55.8 (flavan-3-ols), 17.7–33.1 (flavonols), 10.6–80.3 (chlorogenic acid), phloridzin (1.0–9.3), and anthocyanin (0.1–6.5) (McGhie et al. 2005). Many researchers unanimously agree on the fact that a significant diversity in the concentration of polyphenols occurs within different parts of apple fruit.

26.2.1 Fruit

Apple fruits are a good source of phenolic compounds and exhibit considerable diversity of antioxidant properties and polyphenol and tannin contents. The total extractable phenolic content among various apple cultivars has been investigated and is recorded in the range of 110–357 mg/100 g of fresh apple (Podsedek et al. 2000; Liu et al. 2001). A study by Robards et al. (1999) suggests that 90% of polyphenol components of apple constitutes flavanols, with (−)epicatechin and procyanidin B2 being dominant. Polyphenols in the form of catechin, procyanidin, epicatechin, and phloridzin are present in apple flesh, but the concentration of all these is way lower than in the peels. Similarly, apples with the peels are observed to be better in inhibiting cancer cell proliferation than apples without the peels (Johnston et al. 2002). Duda-Choda and Tarko (2007), in their study on Šampion and Idared cultivars of apple, observed that the flesh of the fruit constitutes chlorogenic acid (14% and 53%, respectively), (−)-epicatechin (29% and 10%, respectively), and procyanidin B2 (28% and 14%, respectively), while only a little or no amounts of quercetin glycosides were detected.

26.2.2 Juices

Apple juice is the most common processed product of apple and an important source of antioxidants especially phenolics (Candrawinata et al. 2013). During its processing, very less amount of phenolic compounds is extracted, while most of them remain in the leftover apple pomace. Besides, peel and seeds are separated from the fruit during juice production, which further contributes to low phenolic content (quercetin glycosides and dihydrochalcones) of apple juice. Raw juice pressed from Jonagold apples by any of the processing methods (pulping, straight pressing, or pulp enzyming) shows antioxidant activity was only 3–10% of the total activity of fresh apples (Van Der Sluis et al. 2002).

26.2.3 Seed

Seeds from apple fruit exhibit a rich source of polyphenols (Ehrenkranz et al. 2005) especially phloridzin. These polyphenols present in apple mainly comprise hydroxycinnamic acids; dihydrochalcones; flavan-3-ols that exist in both monomeric ((+)-catechin and (−)-epicatechin) and oligomeric (proanthocyanidin B2) and also polymeric forms; and flavonols (Fromm et al. 2013). In a study carried out by Xu et al. (2016), it is suggested that phloridzin is the principal phenolic compound present in the seeds of apple fruit. Phloridzin content varied between 240.45 mg/100 g dry weight for Golden Delicious apple and 864.42 mg/100 g dry weight for Honeycrisp apple. Various studies also reveal that phloridzin content in the seed is higher than in the peel (Łata et al. 2009) and in the pomace (Diñeiro et al. 2009). Besides, phloridzin apple seeds also contain hyperin and chlorogenic acid.

Differences in total polyphenol content among various seeds can well be related to cultivar, but the maturity of seeds does not influence it. Apple seeds though show a deficiency of quercetin glycosides as reported by many studies (Van Der Sluis et al. 2001; Boyer and Liu 2004).

The antioxidant potential in apple seeds has been reported to be very high, reaching around 3000 mg Trolox × 100/g of fresh weight depending on the cultivar. Peels, however, show two times lower antioxidant potential when compared to seeds, and flesh antioxidant potential doesn't exceed 500 mg Trolox × 100/g. Polyphenols are the predominant ingredients in apple seeds. Phenolic compounds extracted from apple seeds can be commercially used in food or cosmetics. Therefore, further studies on this valuable by-product may lead to significant economic returns apart from preventing any environmental issues caused by the accumulation of apple pomace.

26.2.4 Peels

Apple peel as a by-product is usually disposed of directly as waste. However, many studies suggest that apple peels contain high phenolic content, and show good anti-proliferative and antioxidant activity (Al-Zoreky 2009; Balasuriya and Rupasinghe 2012; Massini et al. 2013). Furthermore, it is also revealed that irrespective of apple cultivars and other characteristics, apple peel contains higher phenolic content compared to the flesh (Kalinowska et al. 2014). Wolfe et al. (2003) reported that peel of apple varieties exhibits higher antioxidant activity compared to the only flesh and flesh along with the peel. It has also been stated that antioxidant and antiproliferative activities of unskinned apples outweigh those of skinned apples. The concentration of total phenolic compounds present in apple peel is also known to be much higher than in flesh (Ju et al. 1996; Escarpa and Gonzalez 1998). Both these facts put in a line that apple peels have more bioactive properties than flesh without the peel.

Therefore, the high content of phenolics, antioxidants, and antiproliferative present in apple peels can impart potential health benefits when consumed and need to be considered as a valuable source of antioxidants. Waste apple peels from the production of apple sauce and canned apple products should, therefore, be considered as a valuable product. Apple peels also show the potential to be used as a functional food or value-added product in the future. As part of this, these peels can also prove potent for the prevention of chronic disease.

26.2.5 Wastes

The cognition increment in buyers related to the food items they consume and the wellbeing consciousness prompted an increased request for food sources containing naturally dynamic compounds, to be specific antioxidants, facilitating the body to battle against oxidative pressure, especially reactive oxygen species (ROS). Novel wellsprings of antioxidants are needed for nourishment and pharmaceutical businesses. Litter from fruits, especially apple, contains significant molecules (fibers, antioxidants, natural colorants, and so forth), which can be separated and cleansed into key fruit products. The incredible food wastes can be exploited as wellsprings of preventive agents, depending on scientific confirmations concerning the prospects of extraction and purification, health usefulness, and envisioned the possibility of antioxidants obtained from these wastes. Fruit wastes as a spring of naturally active elements with wellbeing-enhancing uses can be exploited as practical ingredients (Banerjee et al. 2017). The apple leftover usually is a heterogeneous mixture of pomace, peels, and seeds. Apple leftover/waste obtained after a juice extraction was tried on colon cancer HT115, HT29, and CaCo-2 cell lines. The outcome obtained indicated that waste compounds are helpful to confer protection against DNA dysfunction, to enhance value barrier function, and to hinder cell attack (Wolfe et al. 2003). Contrasting the inhibitory impacts of non-extractable cancer prevention agents/antioxidants with extractable antioxidants from a freeze-dried apple waste on HepG2, HeLa, and HT-29 human malignant growth cells, non-extractable antioxidants were more effective in generating desired outcome (Olsson et al. 2004). Apple strip/peel waste could likewise be an incredible source of bioactive compounds that may upgrade the human wellbeing (Ravindran and Jaiswal 2016). HT-29 colon cancer tissue showed a positive response to the apple strip/peel juice from ten distinct concentrates of fruits which were tried. Apple fruit waste is mostly made out of peels, seeds, pomace, and so forth. Vital naturally active compounds present in wastes are polyphenolic complexes, fibers, carotenoids, ascorbic acid, and other bioactive compounds having beneficial products. Carotenoids as bio-pigments are imperative for the wellbeing of humans because of their antioxidant features. Polyphenols are another category of bio-pigments having great scavenging ROS spp. activity (free radices), appropriate for foodstuffs due to their antioxidant characteristics. Polyphenolic concentrates from apple wastes enhance storability by regulating discoloration and oxidative progression. The pomace of apple, a residue from squeezed apple can be utilized to make products that could act as a biocompatible platform for osteoblasts. Fruit business establishments generate a lot of waste that influences landfills, containing 80% hemicellulose and sugars, 9% cellulose, and 5% lignin, being decomposable; they elevate methane and generally have great biological oxygen demand(BOD) and chemical oxygen demand (COD) valves which lead to huge retrieval costs. Approximately 75% of apples can be changed over to juice, and the remaining, called pomace comprises around 20–30% dry matter, is utilized basically as feed for animals or as organic fertilizer. As apple pomace is produced in tremendous amounts and holds a large portion of water, it presents stockpiling issues and necessitates prompt actions to avoid putrefaction. A substitute for high environmental attention is its conversion into value-added wares, therefore, lessening the size of waste (WAPA 2016).

26.2.6 Antioxidant Properties of Products Prepared from Apple

Dried pomace acquired by squashing peeled apple fruits is amalgamated with confectionery products such as muffin, bun, and cookies for value addition. Dehydrated apple pomace mixed products exhibited better radical scavenging activity and cyto/DNA protectivity than unmixed products due to the presence of polyphenols in it; the increased concentration of caffeic acid positively conferred to H+K+-ATPase inhibitory activity (Sudha et al. 2016), thereby minimizing the gastric ulcers. Free radicals produced during persistent illness can cause cellular and DNA impairment by attacking them (Harish Nayaka et al. 2010). The protection against various health hazards can, therefore, be anticipated by consuming antioxidant components from apple pomace-based products.

Apple puree, an intermediary product for the making of various juices, nectars, apple sauce, baby food, and other products, contains most of the antioxidants like chlorogenic acid (20.0 mg/100 g), epicatechin, procyanidin quercetin, and cyanidin glycosides in lower concentrations in Idared, while Sampion purees contain higher total phenolics (142 mg/100 g) and procyanidin (17.3 mg/100 g) than the Idared ones (Oszmianski et al. 2007). The chemical characteristics and antioxidant activity exhibited by some apple products are presented below (Santini et al. 2014).

26.3 Characterization of Chemical Compounds Involved in Antioxidant Activity and the Pathways Involved in Biological Activities

One of the major causes of some common, occurring diseases including atherosclerosis, arthritis, diabetes, cancer, gastric ulcers, neurodegenerative, and inflammatory diseases is the oxidative stress caused by the activities of reactive oxygen species (ROS). ROS are very unstable chemically reactive species containing oxygen and rapidly react with DNA, membrane lipids, and proteins causing their oxidation. Examples include peroxides, superoxides, hydroxyl radicals, singlet oxygen, and alpha-oxygen. ROS are inevitably produced in biological systems. They have one missing electron and to get this electron they attack the body cells causing cumulative damage which ultimately leads to chronic diseases. Antioxidants sometimes called as free radical scavengers on the other hand scavenge the ROS and free radicals by contributing their electron and thus neutralizing them, thereby preventing the body cells from damage. Realizing the incredible importance of antioxidants for the improvement of human health and the natural products which are the sources of these antioxidants, the markets have shifted their focus on products having nutraceutical properties. The ability of these products to reduce the incidence of infection has encouraged researchers to identify, quantify, and specify chemicals with antioxidant properties.

26.3.1 Determination of Polyphenols and Antioxidant Capacity

The polyphenolic molecules can be detected using liquid chromatography mass spectrometry (LC-MS) or gas chromatography mass spectrometry (GC-MS). To evaluate the antioxidant activity, different capacity assays viz., DPPH (1,1-diphenyl-2 picrylhydrazyl), ABTS (2,2′,-azino-bis 3-ethylbenzothiazoline-6-sulphonic acid), and FRAPs (ferric-reducing antioxidant powers) are usually employed methods. These methods give an estimation of the radical sequestration ability of the sample.

26.3.2 Characterization of Chemicals with Antioxidant Properties

Considering the importance of antioxidants in the human diet, it is important to characterize the chemical compounds having the antioxidant capacity to assess their potential use in the nutraceutical formulations and food industry. Based on a study on new and old cultivars of apple, around 20 major polyphenols were determined. The main polyphenols identified in the peel were quercetin glycosides (203 ± 108 mg/100 g) and phenol carboxylic acids (10 ± 5 mg/100 g) in the plant tissues. Flavonols present in the peel and vitamin C present in the flesh were found to be the major patron to the antioxidant ability in apple varieties studied. The old apple cultivars were found to have up to 30% stronger antioxidant capacity compared to new ones (Kschonsek et al. 2018). Characterization of antioxidant molecules in fruits (seed, peel, and flesh) of apple cultivars Idared and Sampion showed that seeds have a significantly higher antioxidant capacity as well as higher polyphenol content when compared to their peel and flesh. Phloridzin (84% and 72%) and quercetin (54% and 38%) were predominantly found in seeds and peel, respectively. ABTS but not DPPH, radical scavenging capacity tends to decrease during ripening of apples, while cold storage was found to increase the antioxidant potential (Duda-Chodak et al. 2011). Some specific phenolic compounds are known to increase disease tolerance in apple fruits. One such polyphenol is Phloridzin. It is a chalcone derivative and is known to increase disease resistance in apple. It is a phytoalexin providing resistance to fungal, viral, bacterial diseases—*Venturia inaequalis* and fire blight of pear. Additionally, phlorizin causes inhibition of lipid peroxidation which indicates its antioxidant ability. Characterization of polyphenols and evaluation of antioxidant potentiality in 22 apple cultivars revealed that all the cultivars had a good amount of polyphenols, especially phenolic acid, flavan-3-ols, flavanols, and triterpenoids. Skin color in cherry and its organoleptic qualities are attributed to the accumulated concentration of phenolic compounds in the fruit. Evaluation of polyphenolic components and carotenoids in sweet cherry cultivars whether local or commercial showed that comparatively commercial cherry cultivars had a high concentration of polyphenols, flavonoids, as well as anthocyanins and at the same time had higher antioxidant potential. Polyphenol content in fruits was strongly and positively correlated with the fruit antioxidant activity confirming the fact that polyphenols are strong antioxidants (Tober et al. 2019). Grapes in combination with apples are widely taken all over the world. Antioxidants found in grapes are effective against many diseases. These antioxidants predominantly include polyphenols that are mostly evaluated for their antioxidant properties. Antioxidant activities may vary depending upon the variety. Free radical scavenging and antioxidant activities of 30 grape varieties were evaluated and results indicated that the 30 grape varieties showed diverse ferric-reducing antioxidant powers values, Trolox equivalent antioxidant capacities, total phenolic contents values, and total flavonoid contents. Grape varieties Pearl Black Grape, Seedless Green Grape, Pearl Green Grape, and Seedless Red Grape exhibited strong antioxidant activity, therefore could serve as important sources of antioxidants (Qing et al. 2018). Antioxidants present in berries may help to reduce oxidative stress. Berry consumption should, therefore, be increased in the human diet. The phytochemical composition of some commercial juices of berries was evaluated and associated with their antioxidant properties. The tested juices inhibited DPPH free radical which indicates their property of being good antioxidants (Luis et al. 2018). Phenolics in many fruits are present insoluble as well as bound forms. Although the bound phenolics play a significant role in improving digestion, the reports on phenol concentration and antioxidant properties in fruits are determined on soluble free phenolics. Characterization of the antioxidant properties of the phenolic compounds in some citrus peels shows that bound phenolics in orange peels had significantly higher radical scavenging ability. Grapefruit peels had the highest OH scavenging ability (Oboh and Ademosun 2012). It could be said that bound phenolics, together with the free phenolics, contribute to the well-known medicinal properties of the citrus peels. The detection and evaluation of phenolic compounds in pear samples showed that chlorogenic acid was the major component in the pear samples. The highest flavonol concentration was found in pear samples of the cultivar "Grabova" (Liaudanskas et al. 2017).

26.4 Health Benefits

Due to a significant amount of phytochemicals present in apple, it provides several health benefits. Certain vital benefits are:

Anti-cancer Property Apple consumption possesses potential cancer prevention agents. Apple consumption is associated with the minimized occurrence of oxidative stress (Feskanich et al. 2000). Quercetin and its derivatives are present in large amounts in onion and apple approximately 65%. People taking more onion and apple were found less incidence of bronchial cancer. The respiratory organs have a deduction of 40–50% cancer, who consume a greater amount of apple, grapefruit, and onion (Le Marchand et al. 2000). Apple catechin plays a significant role in decreasing epithelial bronchial stress.

Cardiac Diseases Apple intake has been closely related to the prevention of coronary heart diseases by numerous scientists. Aprikian et al. (2003) found apple pectin and phenolic compounds diminish lymph and hepatic cholesterin, triacylglycerols, and there is apparent cholesteryl alcohol ($C_{27}H_{46}O$) absorption to a greater limit. The flavonoid consumption was associated with a reduced fatality from cardio disease in senior citizens in a Zutphen elderly study (Hertog et al. 1993). Cardiovascular diseases can be decreased by the protective effect of apple due to its cholesterol-lowering ability. Liver cholesterol and plasma cholesterol drops in the case of rats fed with lyophilized apples, but there was an increase in high-density lipoproteins (HDL). Moreover, cholesterol excretion accelerated in the poop of rats fed with apples resulting reduction in cholesterol absorption (Aprikian et al. 2001). Apple being higher in cholesterol-lowering effects compared to pear and peaches as all are having the same roughage content but apples are rich in polyphenols intimating that it may be due to phenolics present in apples (Leontowicz et al. 2000). In the case of women coronary mortality and total flavonoid intake have a significant inverse relation. Apple and onion also have an inverse relation with coronary mortality in the case of women (Knekt et al. 2000). There is also an inverse association between apple juice and wine consumption with fate from cardiovascular diseases in postmenopausal women (Arts et al. 2001). Consumption of flavanols like D-Catechin ($C_{15}H_{14}O_6$) and (−) – epicatechin, both derivatives of apple, have a strong inverse relationship with cardiovascular disease. While net catechin intake has an inverse association with cardiac disease mortality.

Asthma and Emphysema Phytochemicals and polyphenols in apple have been linked inversely with broncho constriction and positively with general lung health. In a study by Woods et al. (2003), apple and pear consumption was linked with a lower incidence of non-allergic and occupational asthma and extrinsic allergic alveolitis (EAA). Both apple and pear consumption was linked with the reduced pitfall of allergic asthma and downscale in bronchus hyperreactivity. Some peculiar antioxidants like tocopherol, ascorbic acid, vitamin A, and provitamin A were not related to allergic alveolitis, but carotene intake has positively linked with asthma. Antecedently apple consumption and selenium intake cause a reduction in asthma in adults (Shaheen et al. 2001). Consumption of apples and oranges reduces the occurrence of asthma in both men and women. Intake of flavonoids especially quercetin, hesperetin, and naringenin mainly reduces the risk of asthma. Apple and pear consumption has positive linkage with alveolar function and negatively related to chronic inflammatory lung disease. Consumption of flavanol especially catechin can control lung diseases and inversely associated with chronic obstructive lung disease (COLD). Apple, citrus juice/squash intake was positively correlated with lung function measured in spirometry (helpful in assessing breathing patterns that distinguish conditions like pulmonary fibrosis, cystic fibrosis, COPD).

Diabetes Mellitus and Emaciation A major component of apple peels, quercetin, has been associated with a decreased risk of type II diabetes. In a study involving 10,000 individuals, apple was associated with a reduced risk of type II diabetes (Knekt et al. 2002). As a major constituent of apple peels, quercetin intake was linked with reduced risk of type II diabetes. In another study conducted on women it was found that women who eat at least one apple every day are 28% less likely to develop type II diabetes than those who do not (Moura 2003).

Immunity Booster In a study conducted by Boyer and Liu (2004), apples, due to the presence of quercetin, were found to help fortify and boost immunity.

Antioxidant Activity Intake of apple especially peels has potential antioxidant property and can hamper the growth of hepatic cancer and colorectal adenocarcinomas cells (Eberhard et al. 2000). Antioxidant activity of 100 g apples is equal to 1500 mg of ascorbic acid which is a potent antioxidant contributing below 0.4% to total antioxidant activity.

Antiangiogenic Activity Apple peels have substantial anti-proliferation activity; apple extracts have been related to treatment of Caco-2 colon cancer cells up to a maximum of 43%. In the case of Fuji apple extracts impede Hep G_2 cell mushrooming by 39% and 57% in Red Delicious and no effect on cell escalation in Northern Spy. Apples without peels have less effectiveness in inhibiting Hep G_2 cell augmentation compared with peeled apples (Eberhard et al. 2000). Apple antioxidants directly don’t inhibit cancerous growth instead indirectly hinder cell expansion by producing oxydol in reaction with media extracts (Wolfe et al. 2003).

Other Manner Benefits Apples boost gum health, beat diarrhea and constipation, improve memory and prove to be anti-cholesterol.

26.5 Conclusion

Antioxidants are the substances that can inhibit the oxidative processes with the living body as well as in various food products. The fruits, particularly apples, contain big flavonoids and phenolic acids. Besides this, apples tend to be a simple source of antioxidants due to their widespread abundance and comparatively low prices. Polyphenols are the major compounds that contribute to the antioxidant potential present in apples. It is generally referred to that their concentration depends on a fruit’s cultivar and species, as well as on fruit maturity, methods of production, soil, and climate conditions. Phloridzin is a prevalent phenolic compound in apple seeds, while chlorogenic acid, (−)-epicatechin, and procyanidin B2 predominate in apple flesh. Apple peels’ antioxidant potential is much higher, varying from two to six times greater than that present in the flesh, which however depends on the apple variety. Quercetin glycosides are a significant fraction of polyphenols in apple peels, but as far as seeds and flesh are concerned, they are either present only in trace amounts or not. Based on the enormous composition and distribution of various polyphenols, apple fruit and its byproducts like juice, pomace impart a wide range of health benefits like anti-cancer properties, fight against various diseases like cardiac issues, asthma and emphysema, diabetes mellitus, and emaciation.

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Apricot

27

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Abstract

Apricot is a stone fruit and member of family Rosaceae closely related to peaches, plums, cherries, and almonds. Common apricot has been reported to grow in geographically diverse areas and climates, ranging from deserts of Central Asia to humid areas of China and Japan and cold winters of Siberia to subtropical climate of Northern Africa. Production of apricots varies from region to region. From last 25 years (1994–2018), Turkey with its temperate climate has dominated world-wide apricot production with over 13 million tons followed by Iran with more than 7 million tons. Apricot is a delicious fruit with multiple and diverse uses amid large portion of global production preserved by drying. Apricots consist of balance of sugar, fibers, proteins, vitamins, minerals, acidity, and strong apricot aroma. Carbohydrates occur in range of 11–13% and are rich source of energy. Fresh fruits are excellent source of vitamin C and vitamin A. Apricots are consumed as fresh, as jams, dried, or fruit bars. Fiber content in apricots, besides providing roughage, stimulates gastric mobility and helps in prevent constipation. Soluble fiber from these fruits lowers blood cholesterol, reduces body weight, and helps in maintaining blood pressure. It is highly enriched with essential minerals like potassium, phosphorous, magnesium, calcium, iron, and selenium, at the same time sodium, zinc, manganese, copper, and iron are also present in small amounts. Different parts of apricot have been reported with significant antioxidant activities which have been attributed to the presence of phytochemicals like

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fatty acids and sterols, polyphenols, sugars, volatile components, and cyanogenic glycosides. In addition to antioxidant activities, anticancer, cardioprotective, anti-inflammatory, hepatoprotective, antinociceptive, and antimutagenic effects have been reported from different plant parts of apricots.

Keywords

Apricot · Phytochemicals · Antioxidant activities · Anti-inflammatory · Antimutagenic

27.1 Introduction

Apricot is a stone fruit and member of Rosaceae family, closely related to peaches, plums, cherries, and almonds. Apricots have smooth velvety skin, naturally sweet flavor, and soft flesh. Apricot (*Prunus armeniaca* L.), the most commonly cultivated species, needs fairly cold winter and reasonably high temperatures in spring and early summer (Guclu et al. 2006; Ahmadi et al. 2008). Apricot has been named as such by Romans from "praecocia," which in Latin means "early matured"; or "albarquq," which in Arabic means "short ripening period." Cultivation of apricots in subtropical climate regions is not suitable. It needs relatively cold winter for apt dormancy and flower bud development. Common apricot has been reported to grow in geographically diverse areas and climates, ranging from deserts of Central Asia to humid areas of China and Japan and cold winters of Siberia to subtropical climate of Northern Africa (Cheng et al. 1990). Apricots are mostly successful in Mediterranean climates while some cultivars are more often than not restricted in a geographical area with certain ecological conditions (Layne et al. 1996). Apricots are consumed in fresh, frozen, or dried form and are also used for preparation of jellies, jams, pulp, juices, and extruded products (Chauhan et al. 2001). Apricot is nutritious fruit with various health benefits. Its kernels are excellent source of oil used for cooking purposes and production of some cosmetic products. Apricots have many attributes and qualities like attractiveness, tasty flavor, multiple-use functionality, and non-surplus production. Nevertheless, apricots have higher sensitivity to different diseases as compared to other fruits, leading to irregular market supply and low consumption rate as compared to other summer fruits (Audergon et al. 2006; Moreau-Rio 2006). Apricot is highly adaptable and tolerates ranges of soil and climatic conditions. It has high ecological and economic importance in dry temperate regions. Improved cultivars and breeding play a key role in development of growing apricot industry. Apricot is rich in carbohydrates and a good source of fibers, vitamins, and minerals. Besides, bioactive phytochemicals have been found in apricots which play key role in biological systems and are effective in preventing oxidative stresses (Leccese et al. 2011). This chapter provides an insight about apricot with emphasis on phytochemical profiling, antioxidant properties, and health benefits.

27.1.1 History

Even though apricot (*Prunus armenica* L.) is thought to have Armenian origin, but the history of its cultivation dates back to thousand years in Asia (Hormaza et al. 2007). Apricots were a major fruit staple in China by 600 BC, eaten fresh, salt-cured, smoked, or dried (Faust et al. 1998). China and Central Asia from Tien Shan mountainous region to Kashmir is its most likely origin (Vavilov 1951). These regions represent two primary centers of domestication of apricot cultivars, whereas Near Eastern region from Iran to Turkey are portrayed as secondary centers of origin and diversification (Bailey and Hough 1975). Cultivation of apricots in Europe is relatively recent phenomenon (2000 years), hence its native range is not easy to decipher as apricots were comprehensively cultivated prior to any historical record. Three to six centers of origin have been proposed in the literature (Vavilov 1951; Bailey and Hough 1975; Vavilov et al. 1992), however, different places of origin are unlikely. Central Asian center or Tien Shan Mountains represents its true center of origin and others represent radiation of species to different regions. Inner Asiatic region consists of Afghanistan, Uzbekistan, Tajikistan, and northwestern India. Asia Minor region represents third region with countries Iran, area in the Caucasus region between Black and Caspian Sea, Turkmenistan, and its namesake Armenia as well. Classifications so formed concur well with delineations based on traits of fruits (Kostina 1969). Apricot came to Iran and Europe from Central Asia as part of military and cultural expansion of Alexander the Great into Turkistan during fourth century BC (Janik 2005; Yilmaz and Gurcan 2012). It has been prized commodity in Iran, which remains one of the leading producers of apricots. Expansion of apricot into Europe seems to occur at two different times. Romans in first century AC came to know about it by fighting wars with Persians. From Rome, it reached Spain between second and fourth century AC. Arabs also introduced apricot in Spain from North Africa; afterwards it reached to America, South Africa, and Australia (Mehlenbacher et al. 1991; Lichou and Audubert 1992). It has been proposed that some cultivars of the present time originated directly from primary origin centers, while others may have bred from hybridization of genotypes in secondary centers. English settlers introduced apricots to the New World as they bought crop to the new colonies in Eastern North America, but it never prospered. However, it became productive and fruitful in New World cultivation when it was ferried to settlements on the Pacific Ocean by Spanish missionaries where it prospered and remains valuable species till date (Boriss et al. 2006; Bird et al. 1995). Most of the time trading and commerce resulted in introduction of apricots in England and United States (Virginia) in the seventeenth century (Mehlenbacher et al. 1990). Later on, Spaniards introduced it in California in eighteenth century. The Japanese apricot has been cultivated for 3000 years, and wild forms can still be found in mountains. It originated in southern China in more warm and humid weather conditions than *P. armenica* (Zhao et al. 2005). An investigation of original Chinese germplasm, population structure of wild apricots of Ily valley in west China, and molecular data on crop-wide germplasm diversity all agree with the theory of western Tien-Shan wild populations as major ancestral gene pool in Central Asia for apricot domestication and also responsible for its spread to the westerly regions (He et al. 2007; Zhebentyayeva et al. 2003; Zhebentyayeva et al. 2012).

27.1.2 Production – World and India

Apricots are delicious fruits with several healthy ingredients, making it one of the precious fruits worldwide. Even though its cultivation is wide-reaching, but most of the production is dominated by Mediterranean area, with Turkey the leading producer (Statistics 2019). Temperate climate is best suited for this fruit. Mediterranean areas are usually dominated by hot summers with cold and wet winters; consequently, apricots thrive in these areas. Cold-induced dormancy incurred in Mediterranean and Asian climates is perquisite for apricot flowering. Temperature fluctuations over the parts of North America make it less suitable for apricot production and thus limit its cultivation range. Last 20 years have seen an increased world production of apricots due to large plantings in Asia and Africa. North America and Oceania countries have reported decreased production whereas in Europe production has increased but at lower rates (Yearbook, FAO Production 1989). Germplasm technology has made it possible to grow apricots in diverse climates, hence making it capable of contributing more and more to the world's fruit production. The introductions of new cultivars often give disappointing results owing to limited ecological adaptation at genotype level (Pennone et al. 2006). Accordingly, cultivars must be bred for each marketing opportunity and each producing area.

Production of apricots varies from region to region. From last 25 years (1994–2018), Turkey with its temperate climate has dominated worldwide apricot production with over 13 million tons followed by Iran with more than 7 million tons. Besides these two, top producing countries include Uzbekistan (7 million tons), Italy (5 million tons), France (4.5 million tons), Pakistan (4.4 million tons), Algeria (3.8 million tons), Spain (3.4 million tons), Morocco (2.6 million tons), and Japan (2.1 million tons) (Fig. 27.1) (FAO 2019). These regions have specifically adapted varieties which are well adapted to the prevailing climatic conditions. In India, climatic conditions vary with tropical in south and temperate in northern regions. Apricot trees have been reported to grow at 6000 m altitude and even survive a chilling temperature of −35 °C (Kumar et al. 2009). Even though, production of apricots in India from last 25 years (1994–2018) is on increasing trend, 7000 tons in 1994 to 15,958 tons in 2018, it still lags far behind from the top producers in world. India has contributed only 292,442 tons of apricot production in last 25 years which accounts for less than 1% to the worldwide production of what top 10 countries contributed (Fig. 27.2).

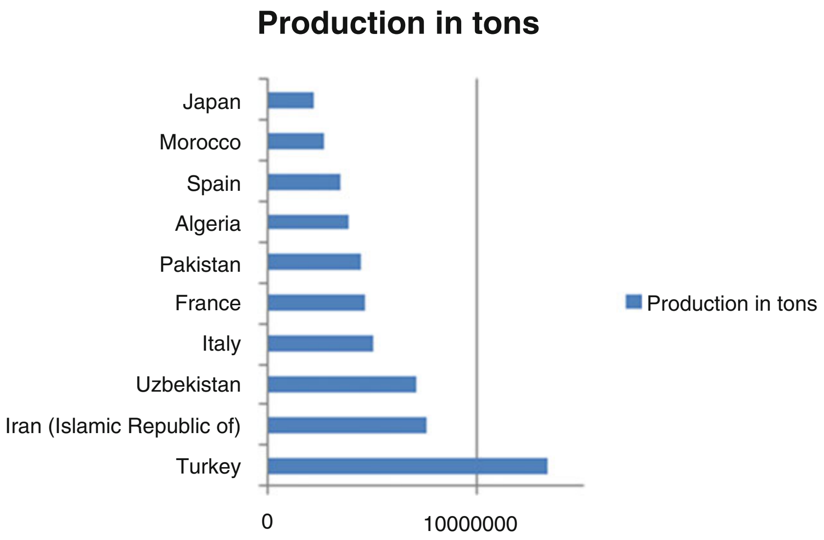
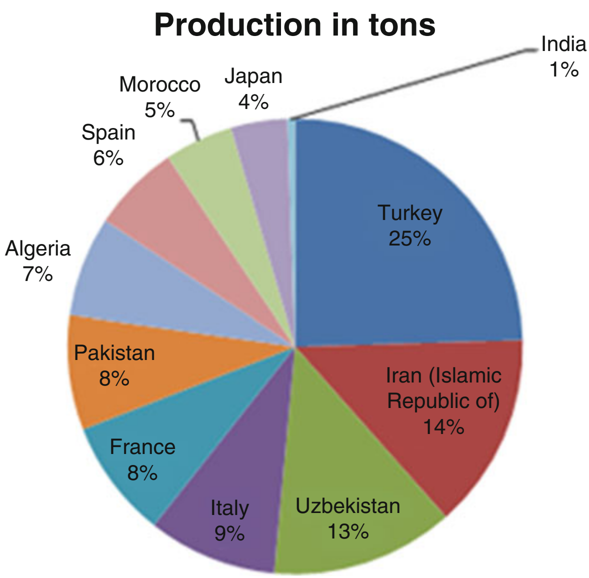


Fig. 27.1 Apricot production from top 10 countries worldwide (1994–2018)

Fig. 27.2 Production share of apricots of India compared with top producers worldwide



27.1.3 Botanical Description

Apricot, scientifically known as *Prunus armeniaca*, was first brought into play by Gaspard Bauhin in 1623 in his book *Pinax Theatri Botanici*, in which he referred the species as *Mala armeniaca* or *Armenian apple*. Later on, Linnaeus in 1753 took up Bauhin's epithet and named it *Prunus armeniaca* in his first edition of *Species Plantarumi* (Linnaeus 1753). Owing to their extensive ranges and adaptations, apricot plants have defied botanical classifications. Bailey (1916) used leaf shape to differentiate various cultivars, whereas Redder (1940) separated plums from apricots on the basis of ovary pubescence (Bailey and Sinnott 1916; Rehder and Dudley 1940). Recently comprehensive comparisons provide by Ledbetter (2008) illustrated the inapplicability of various botanical descriptors for the classification of apricots. Apricot belongs to family Rosaceae, section Armeniaca, subgenus Prunophora Focke, and genus *Prunus* L. (Rehder and Dudley 1940). Rosaceae is one of the largest families of angiosperms and includes more than 3100 species and encompassing almonds, apples, peaches, plums, cherries, and berries distributed mostly throughout northern temperate regions of world (Hummer and Janick 2009). Different physiological and morphological characteristics have given rise to complex taxonomic pattern of Rosaceae. Even though, molecular analysis has introduced innovative taxonomical rearrangements, taxonomy in this family is still controversial for some taxon groups (Potter et al. 2007; Shi et al. 2013). Apricot or *Prunus* is contained in subfamily Amygdaloideae also known as Prunoidea. Genus *Prunus* has been further divided into three subgenera recently although it was having five previously (Moustafa and Cross 2019). Prunus and almonds which were earlier placed in subgenus Amygdalus are now positioned into subgenus Prunus having different sections. Common apricot (*P. armeniaca*) and Japanese apricot are included in section Armeniaca. Apricot species are regular diploids with 16 or 8 pair of chromosomes. Based on the classification system, apricot species number ranges from 3 to 12. However, six distinct species are by and large recognized: Tibetan apricot *P. holosericeae* Batal, Briançon apricot or Alpine plum *P. Brigantine* Vill, Manchurian apricot *P. mandshurica* Maxim, common apricot *P. armeniaca*, Japanese apricot *P. mume* Sieb. and Zucc., and Siberian apricot *P. sibirica* L. (Kryukova 1989). Out of these, common apricot cultivars are predominantly grown, though introgression of Japanese apricot and to less extent Manchurian apricot and Siberian apricot into cultivated germplasm is commonly accredited fact among breeders. *Prunus* × *dasycarpa* Ehrh. (also known as black or purple apricot), *P. sibirica* var *davidiana* (Carrière) and *P. armeniaca* var *ansu* (Maxim.) Kost., are other three often recognized species but are apparently of hybrid origin. Moreover, artificial cross pollination has given rise to new interspecific hybrids like "plumcot" a hybrid between apricots (*P. armeniaca* L.) and diploid plums (*Prunus salicina* Lindl.). Likewise, "aprium" and "pluot" are complex hybrids resulting from interspecific crosses of apricots and plums with subsequent back crossing to apricot (aprium) or plum (pluot) (Manganaris et al. 1997; Ahmad et al. 2004). Even though sparse genomic resources are available for apricots, new and innovative technologies permit rapid application of genomic tools to apricot productivity and breeding programs and help in resolution of gene functions and mitigation of barriers threatening apricot production (Folta and Gardiner 2009).

Common apricots are small or medium-sized trees, reaching heights of about 14 m in native ranges. Leaves have long red-purple petioles and serrate margins. Perigynous flowers are borne by apricots with 30 stamens which emerge from the hypanthium and one pistil with solitary carpel. Two ovules are present in apricots but more often than not only one seed is produced. Floral buds initiate in late spring or summer. It requires chilling to initiate flowering, following which little heat is required to bloom. Apricots are prone to freezing, and therefore their production is limited by risk of spring frost. Fruit of apricot is known as drupe, consisting of exocarp (skin), fleshy mesocarp, and an endocarp which is hard and stony. Fruit flesh is sweet or tart with color mostly orange.

27.2 Health Benefits

Apricot is a delicious fruit with multiple and diverse uses amid large portion of global production preserved by drying (Faust et al. 1998). Apricots consist of balance of sugar, fibers, proteins, vitamins, minerals, acidity, and strong apricot aroma (Moustafa and Cross 2019). Carbohydrates occur in range of 11–13% and are rich source of energy. Fresh fruits are excellent source of vitamin C and vitamin A (Wills et al. 1983). Apricots are consumed as fresh, jams, dried, or fruit bars. Fiber content in apricots, besides providing roughage, stimulates gastric mobility and helps in prevent constipation (Akin et al. 2007; Tamura et al. 2011). Soluble fiber from these fruits lowers blood cholesterol, reduces body weight, and helps in maintaining blood pressure. It is highly enriched with essential minerals like potassium, phosphorous, magnesium, calcium, iron, and selenium, at the same time sodium, zinc, manganese, copper, and iron are also present in small amounts (Munzuroglu et al. 2003; Ali et al. 2011). Apricots are enriched with more than 200 compounds like alcohols, esters, and aldehydes, even though their concentrations vary in different cultivars (Guillot et al. 2006). β-carotene is the main pigment in apricots followed by c-carotene and β-cryptoxanthin. It has been reported that apricots attenuate apoptosis or cell death and oxidative stress when combined with radiotherapy in liver carcinogenesis. In another study, 5% dried organic apricot food supplementation for 3 weeks has positive effects on liver regeneration. Kernel extracts of apricots have been reported to have anti-inflammatory effects and could play possible role in bowel disorders. Apricots are also vitamin rich with vitamins A, C, K, E, and B complex vitamins – riboflavin, thiamin, pyridoxine, niacin, folic acid, and pantothenic acid reported. In addition to malic acid and citric acid, organic acids like succinic acid, tartaric acid, oxalic acid, galacturonic acid, malonic acid, and fumaric acid have been reported from apricots (Fatima et al. 2018). These organic acids from nutritional point of view maintain acid–base balance in intestine and improve uptake of iron from gut.

Antioxidant properties have been attributed to its phytochemical composition and numerous studies have revealed its free radical scavenging activities and thus used as functional food. Apricot has been used since ages in China and adjacent countries for use as analgesic, antiasthmatic, antipyretic, antiseptic, emetic, expectorant, laxative, etc. Used as a medicine, it is thought to helpful in regenerating body fluids, quenching thirst, and detoxification in China. Phenolic components in apricots, namely, β-carotene, chlorogenic acid, and lycopene have been reported to prevent oxidation of low-density lipoproteins (LDL), thus improving antioxidative status of the body and helps in combating cardiovascular diseases. In addition, fiber content both soluble and insoluble also reduces cholesterol and LDLs. Apricots have also been shown to reduce neutral fats in liver and are thus quite effective in treatment of hepatic steatosis in animal models (Angulo 2002). Flavonoids and flavones present in apricots besides reducing risk of cardiovascular disease and lung cancer, help in regulating homeostasis. Apricots owing to their constituents and ingredients with antioxidant activity and compounds like anthocyanin and carotenoids, as well as procyanidins with hypoglycemic activity have been used as a healthy food for diabetic patients, thus reducing diabetic complications. Apricots in some studies have shown anticarcinogenic potential. Miyazawa et al. (2006) examined the role of compound Syringaresinol, isolated from Japanese apricot in motility inhibition of *Helicobacter pylori*. Likewise, Japanese apricot fruit juice concentrates prevented *H. pylori*–induced stomach lesions in Mongolian gerbils (Otsuka et al. 2005). Apricots have inhibitory effect on stomach mucosal inflammation and gastritis progression when infected with *H. pylori* (Enomoto et al. 2010). Apricot seeds and kernels have been used in pathological disease like bronchitis, asthma, leprosy, colorectal cancer, leukoderma, infant virus pneumonia, and intestinal pain (Chang et al. 2005). Likewise, apricot oil was used in England to treat ulcers and tumors during seventeenth century and for treating dermatitis (Harbeck 2001; Yildirim et al. 2007).

27.3 Antioxidant Properties of Apricot Fruits, Juices, Seeds, Peels, Wastes, and Apricot Products

Approximately 80–85% of global dry apricot and apricot export takes place from Malatya (Dwivedi and Ram 2008). Quality of the fruit is assessed on the basis of its external appearance, taste, texture, and color. Characteristically, the fruit varies in deliciousness, pleasant smell, and shows variations of colors ranging from yellow to orange with a random overlay of red color. Apricots are edible plants, and mostly the fruit of the plant is eaten by humans. There are different ways by which humans consume apricots, including fresh fruit, dried fruit, kernels, juices, peels, flesh, and essential oils extracted from either mesocarp or endocarp. Herein, significant biological activities including antioxidant activity of apricots have been summarized. The apricot fruit as a whole including kernels are a source of wide range of fatty acids, fiber, soluble sugars, proteins, and oil (Femenia et al. 1995; Mandal et al. 2007; Orhan et al. 2008; Turan et al. 2007; Ul'chenko et al. 2009). Different types of carotenoids have also been isolated from apricots, including lycopene, γ-carotene, β-cryptoxanthin, and last but not least β-carotene (an active antioxidant in apricots) (Ul'chenko et al. 2009; Akin et al. 2008; De Rigal et al.

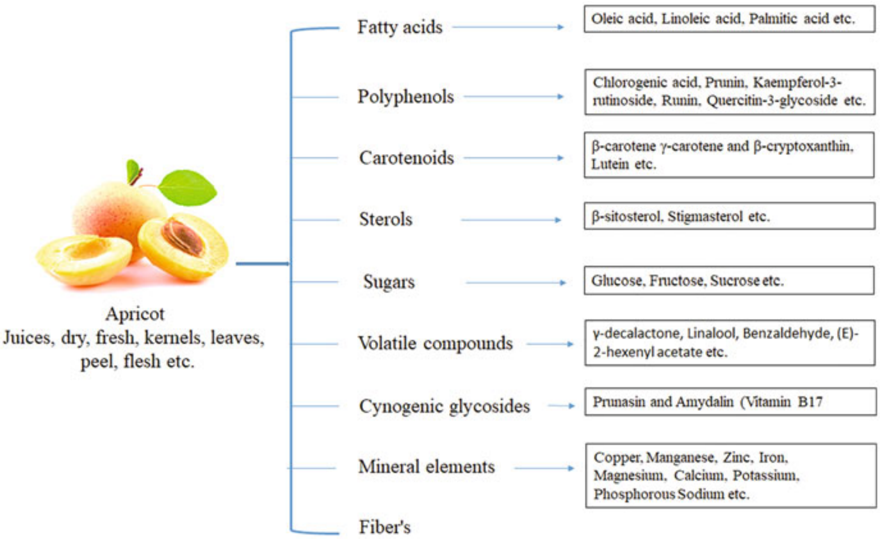


Fig. 27.3 Flowchart representation of chemical composition of apricots

2000; Rafi et al. 2007; Ruiz et al. 2005). Moreover, a number of phenolic compounds were also found in apricots like rutin, (−) epicatechin, (+) catehin, and neochlorogenic and chlorogenic acids (Radi et al. 1997; Liu et al. 2009). Additionally, many mineral elements have also been recognized in apricots including copper (Cu), manganese (Mn), zinc (Zn), iron (Fe), magnesium (Mg), calcium (Ca), potassium (K), phosphorous (P), and sodium (Na) (Ozcan 2000). Polyphenolic compounds including flavonoids, carotenoids like β-carotene, different fatty acids, proteins, and fibers collectively give rise to high antioxidant activity of apricots. Chemical composition of apricots and its kernels is represented in Fig. 27.3.

Different studies have been carried out on antioxidant nature of apricots. The extracted polyphenolic fractions from *P. armeniaca* of Turkey was subjected to antioxidant activity in vitro through 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging (superoxide). No significant activity was recorded through DPPH, while miniscule activity was recorded in case of superoxide ion at 156 mg/mL (Orhan et al. 2003). Several fruits were collected to investigate their antioxidant potential through DPPH, and maximum scavenging activity was recorded in hawthorn, apricots, and blueberries. Five varieties of apricots collected from Malatya region of Turkey, classified as sulfited, sun-dried, and fresh samples, were subjects to determination of antioxidant potential through cupric ion-reducing antioxidant capacity (CUPRAC) and 2,2′-azinobis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) methods. The results revealed remarkable antioxidant capacity on correlation of CUPRAC results with ABTS results (Guclu et al. 2006). Radical scavenging power (RSP), β-carotene bleaching method, reducing power (RP), anti-lipid peroxidative activity (ALPA), and iron (III to II) reducing test systems were used to evaluate the antioxidant potency of roasted, defatted, and peeled apricot kernel flours. The ALPA values were recorded to be decreasing in roasted process and in case of non-roasted were found to be high. Roasting of the kernel flours was recognized with no significant effects on RP and RSP tests (Durmaz and Alpaslan 2007). A screening was performed on ethanol extracts of 64 prepared extracts of Chinese plants for observations of antioxidant properties. Results displayed that bitter apricot seeds extract showed minuscule radical scavenging activity of 5.37% against DPHH and minuscule value of 0.011 mmol/g on dry weight basis against ferric-reducing antioxidant power (FRAP) assay.

27.4 Phytochemical Composition of Apricots

27.4.1 Fatty Acids and Sterols

Gas chromatography mass spectroscopic analysis of *P. armeniaca* (Uzbekistan) seed oil revealed that it contains different fatty acids. The major fatty acids include 61.4% of oleic acid, 26.6% of linoleic acid, and 5.2% of palmitic acid; moreover the oil contained 71.8% of β-sitosterol and 4.3% of stigmasterol (Tsanova-Savova et al. 2005). Twigs and leaves of *P. armeniaca* belonging to Uzbek region were also investigated for their fatty acid content in a similar study and these were found rich in fatty acid content. In a study of 42 types of wild apricots collected from different regions of India, including Nubra, Kargil, and Leh areas in Ladakh and Udaipur, Keylong, and Kullu areas of Himachal Pradesh, fatty acids were isolated in higher quantity. It was observed that the major fatty acid was oleic acid with 52.41% to about 80.76% followed by linoleic acid with 12.19–39.79%. Further, in another study of bitter apricot kernels collected from 10 different apricot-growing areas of Ladakh (India) revealed presence of several fatty acids including eicosenoic acid (minimum amount), palmitoleic acid, palmitic acid, stearic acid, arachidic acid, and linoleic acid (Fig. 27.4).

27.4.2 Polyphenols

Polyphenolic compounds are the main source of antioxidant potential of apricots. Several polyphenolic compounds have been isolated different parts of *P. armeniaca*. Polyphenolic content within apricots was characterized by HPLC, and it led to the recognition of several polyphenolics. The main polyphenolic compounds include kaempferol-3-rutinoside, rutin (quercetin-3-rhamnoglucoside), quercetin-3-glucoside, prunin (naringenin-7-glucoside), (−)-epicatechin, chlorogenic acid (3-caffeoylquinic acid), (+)-catechin, protocatechuic acid, neochlorogenic acid, and chlorogenic acid. In this investigation, the procyanidins B2, B3, and C1, prunin, and protocatechuic acid were isolated for the first time. A comparison of (−)-epicatechin and (+)-catechin content among a variety of fruits assembled from Bulgaria. The outcomes suggested that apricots extract was the chief container of

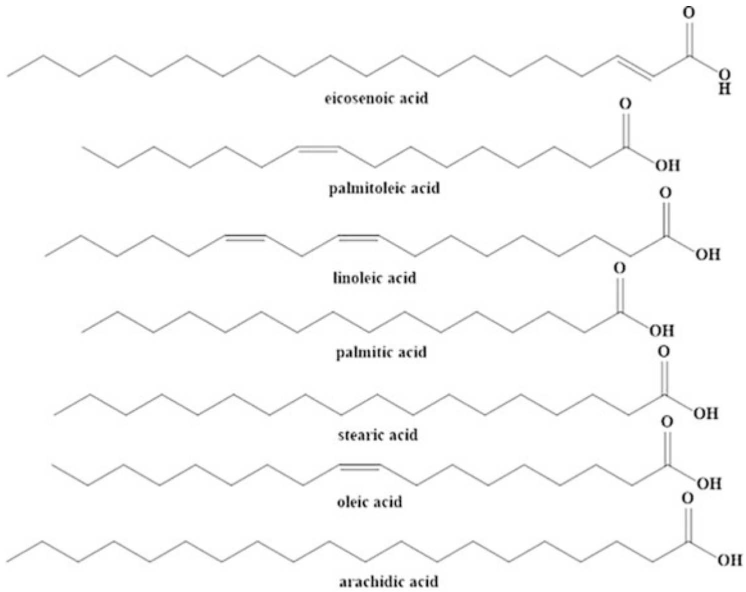


Fig. 27.4 Structure of some of the fatty acids isolated from apricots

these two phenolic compounds nearby 82% and 73%, respectively, after grapes (Veberic and Stampar 2005). Another study on pulp and peel of the apricot fruit detected the presence of rutin, epicatechin, and chlorogenic acid. The amount of these compounds was found in higher quantity in peel than in pulps. HPLC-DAD (diode-array detection) characterization was carried out on 37 different varieties of apricots including four novel releases (Dorada, Selene, Murciana and Rojo Pasion) which were obtained by crossing among variant varieties of apricot with three traditional Spanish cultivars (Búlida, Mauricio, and Currot). Results revealed the presence of principle phenolics including anthocyanins, flavonols, hydroxycinnamic acid derivatives, and procyanidins.

Among these principle compounds, 3-glucoside, cyanidin 3-rutinoside, quercetin 3-acetyl-hexoside, kaempferol 3-rhamnosyl-hexoside, quercetin 3-rutinoside, some procyanidins trimmers, procyanidins (B1, B2, and B4), and neochlorogenic and chlorogenic compounds were isolated from the flesh and skin of the fruit (Ruiz et al. 2005). Different cultivars of apricots were collected in Croatia which represented higher amounts of quercetin-3-rutinoside followed by quercetin-3-glucoside, quercetin-3-galactoside, and kaempferol-3-rutinoside. It was also observed that same cultivars contained procyanidins (B1, B2, and B3) and ferulic, gallic, p-Coumaric, chlorogenic, caffeic, and neochlorogenic acids (Dragovic-Uzelac et al. 2007). Structures of important polyphenolic compounds isolated from apricots are given in Fig. 27.5.

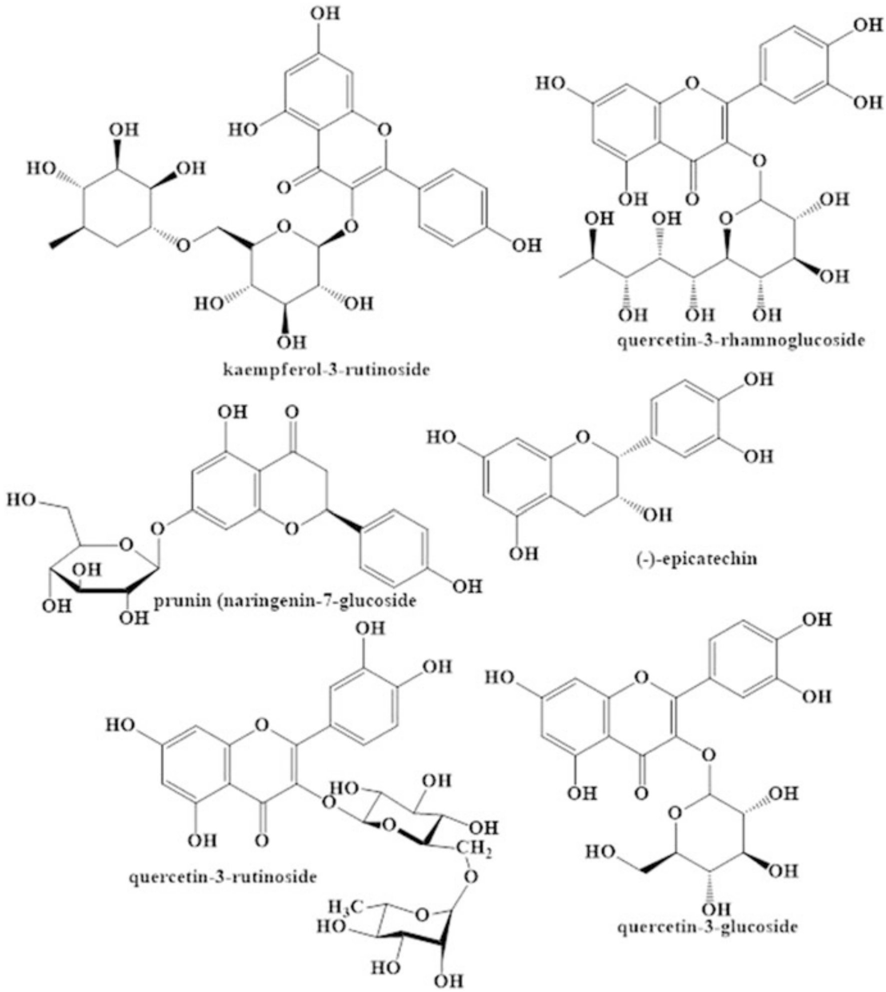


Fig. 27.5 Some of the important polyphenols isolated from apricots

27.4.3 Sugar Content

The apricot samples collected from Italy have been reported to bear 0.27–1.60% of fructose, 0.90–3.13% of glucose, and 1.92–6.92% of sucrose (Bassi et al. 1996). The seeds of *P. armeniaca* were subjected to structure investigation and illustration for acidic polysaccharides. The outcomes presented the presence of 12.5% of glucuronic acid (Fig. 27.6), 37.5% of glucose, and 50% of mannose (Banerjee and Bhatt 2007). A study was carried out in France for determination of sugar content within 28 types of apricot cultivars collected at ripened and unripened stages. Results revealed the presence of 0.53 g/100 g and 0.56 g/100 g of fructose, 1.64 g/100 g and 1.81 g/100 g

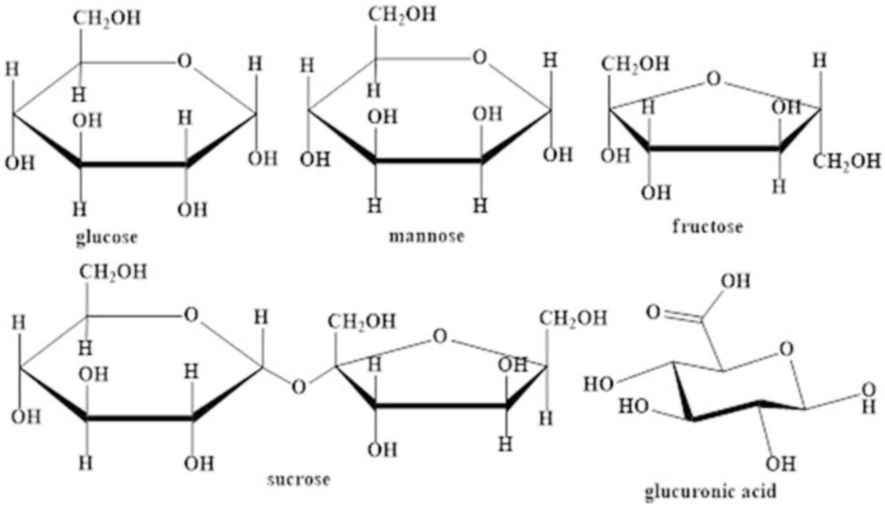


Fig. 27.6 Structure of some important sugars isolated from apricots

of glucose, and 6.36 g/100 g and 6.90 g/100 g of sucrose at ripened and unripened stages, respectively (Aubert and Chanforan 2007).

27.4.4 Carotenoids

In Spain, 30 existing and 4 new releases (Dorada, Selene, Murciana, and Rojo Pasion, obtained through crosses between different existing varieties of apricots in Spain) types of apricots were subjected to carotenoid chemical characterization using HPLC. The overall quantity per 100 g of the apricot extract was 1.5–16.5 mg, with maximum quantity of β-carotene followed by γ-carotene and β-cryptoxanthin (Fig. 27.7) (Ruiz et al. 2006). Three apricot cultivars including Velka rana, Madjarska nabolja, Keckemetska ruza, collected from Croatia were subjected to carotenoid investigations. The results showed the presence of lutein, γ-carotene, and β-carotene, at pre-ripening, semi-ripened, and ripened stages, with maximum amounts of β-carotene. In a study, six different types of apricot cultivars were purchased from a Germany market, including Redsun, Orangered, Moniqui, Harogen, Bergeron I, and Bergeron II, for determination of carotenoid content. Characterization of carotenoids was performed with liquid chromatography mass spectroscopy with DAD and it showed presence of 1.44 μg/g to 39.94 μg/g of β-carotene, 0.06 μg/g to 0.36 μg/g of lutein, and trace to 0.46 μg/g of zeaxanthin. Here, the presence of α-carotene (Fig. 27.7) was not detected in any of the six samples (Kurz et al. 2008).

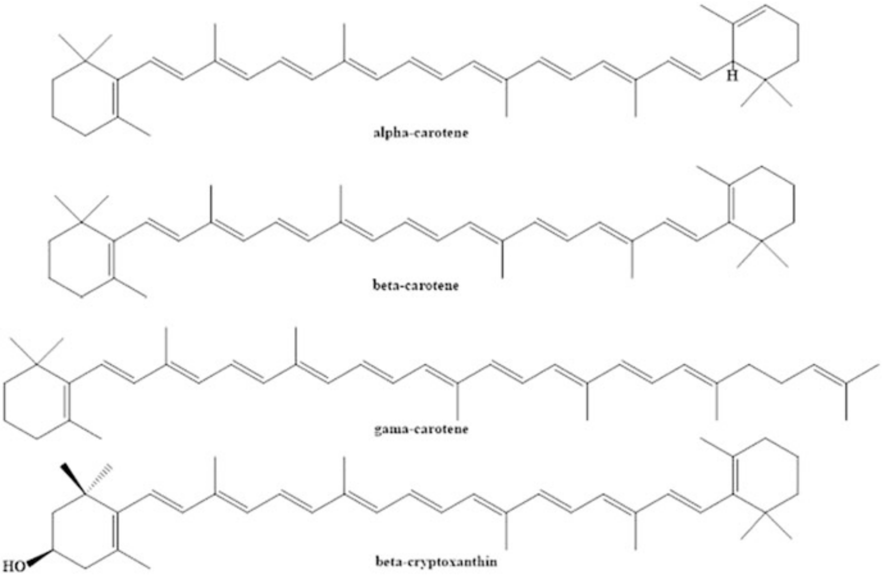


Fig. 27.7 Structure of carotenoids isolated from apricots

27.4.5 Volatile Compounds

Moreover, several volatile compounds have been found in apricots. Study have been carried out on 28 apricot cultivars in France at ripened and pre-ripened stages using GC-MS, GC-FID, LLME (liquid–liquid microextraction). The volatile components in apricot extract, at both ripened and pre-ripened stages, majorly includes γ-Decalactone, linalool, benzaldehyde, and (E)-2-hexenyl acetate (Fig. 27.6) (Aubert and Chanforan 2007). Another study performed in France involved the investigation on eight different varieties of apricots including Goldrich, A4025, Iranien, Double Rouge, Moniqui, Hybride Blanc, Orangered, and Bergeron. The results showed principle content of apricots includes γ-Decalactone, linalool, benzaldehyde, and α-terpineol (Solís-Solís et al. 2007). Another study was carried out on six variant types of apricots from Melgueil and Avignon regions of France including A4025, Rouge du Roussillon, Hargrand, Goldrich, Orangered, and Iranien. It has reported the presence of 10 compounds defined as hexyl acetate, ethyl acetate, limonene, β-cyclocitral, (E)-hexen-2-alwere, 6-methyl-5-hepten-2-one, γ-decalactone, linalool, menthone, and β-ionone (Fig. 27.8) (Guillot et al. 2006).

27.4.6 Cyanogenic Glycosides

Cyanogen glycosides are the main reason of bitterness in the kernels of bitter apricots. Vitamin B17 or amygdalin is the first cyanogen glycoside isolated from

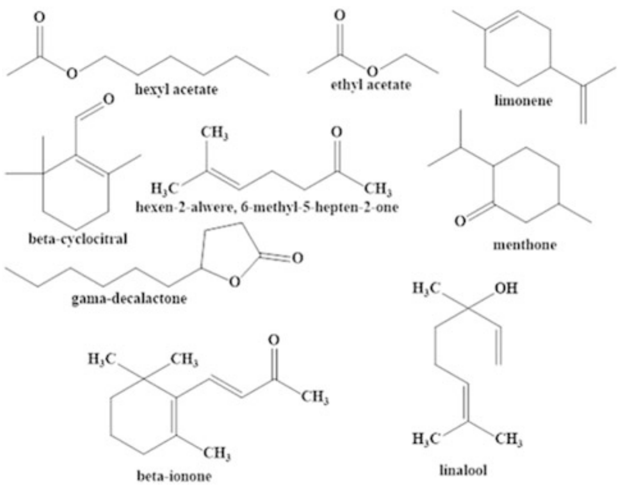


Fig. 27.8 Structure of important volatile components isolated from apricots

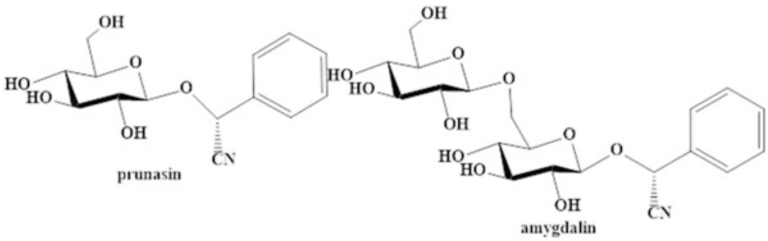


Fig. 27.9 Structure of some cyanogenic glycosides isolated from apricots

P. dulcis and is present in *P. armeniaca* as well (Yan et al. 2006). Almond and apricot kernels are rich source of amygdalin normally about 3–4% weight but in apricot kernels it may rise up to 8%. Prunasin is another type of cyanogen glycoside found in apricots, a study showed that apricots contain 50 μMol/g and 150 μMol/g of prunasin and amygdalin (Fig. 27.9) on the basis of dry weight, respectively (Tuncel et al. 1998).

27.5 Diversity of Biological Activities Exhibited by Apricot Phytochemical Constituents/Extracts and the Pathways Involved

Apricots and its kernels have been recognized with significant pharmacological activities including antioxidant, renoprotective, hepatoprotective cardioprotective, antifungal, antiatherosclerating, antiaging, anticancer, and antiparasitic. Moreover, apricots have been shown with enzyme inhibition, antinociceptive, anti-inflammatory, antitussive, antimutagenic, antimicrobial, anticestodal, anti-spasmolytic, and sedative effects (Kahlon and Smith 2007; Miyazawa et al. 2006; Yiğit et al. 2009; Yilmaz 2010; Georgiou et al. 2011; Erdogan-Orhan and Kartal 2011; Raj et al. 2012).

27.5.1 Anticancer Activity

Different studies have reported that bioactive compounds isolated from apricots show significant anticancer potential. A study has reported that amygdalin molecule isolated from apricot kernels has significant anticancer potential. It was reported that amygdalin induces its anticancer effects via stimulation of apoptosis by upregulation of proapoptotic (Bax) protein expressions and downregulation of antiapoptotic protein expression (Bcl-2) expression. Amygdalin has been found to induce cell cycle arrest by blocking the cell cycle at G0/G1 check point (Saleem et al. 2018). Amygdalin has been reported to prevent mTOR/AKT signaling pathway and decrease the catenin and integrins. Moreover, its adhesion suppressive effects were seen against breast cancer, bladder cancer, and lung cancer. IT acts as a potential metastasis inhibitor against different human cancers (Chen et al. 2020). A study was carried out to establish the cytotoxic of sweet apricot extracts (ethanol, methanol, as well as water extracts) against three different cancer cell lines including Hep-G2, HCT-116, and MCF-7. Results indicated that all the three types of extracts induced significant cytotoxic effects in all types of used cancer cell lines. The cytotoxicity was very high in case of liver cancer Hep-G2 cells (Gomaa 2013).

27.5.2 Cardioprotective Efficacy

Cardioprotective effects of *P. armeniaca* were studied using urethane-anesthetized rats by ischemia-reperfusion (I/R) injury. Results of the investigation showed that extent of infarct remarkably decreased 10% ($55.0 \pm 4.3\%$) and 20% ($57.0 \pm 2.9\%$) apricot-fed groups compared to control group ($68.7 \pm 2.0\%$). Similar impact was demonstrated by apricot fed groups over I/R injury on investigations through light and electron microscopy. The antioxidant potential of rats which were apricot-fed showed significant enhancement. The activities of antioxidant allied enzymes like CAT, SOD, Zn, and Cu were significantly higher in 20% of group fed with apricots in comparison to control group. The levels of TBARS were also lower in apricot-fed rats than in control group (Parlakpinar et al. 2009). Hence, the cardioprotective effects of apricots in vivo were attributed to their antioxidant potential.

27.5.3 Anti-inflammatory Potential

P. armeniaca seed extract has been shown with important anti-inflammatory potential. In a study, it was examined in lipopolysaccharide (LPS)-induced inflammation mouse model (involving microglial BV2 cells). Outcomes of the investigation signified that the extract significantly retarded the production of nitric acid and prostaglandin E_2 through suppressing the activities of mRNA-inducible nitric oxide synthase, and retardation in augmentation of cyclooxygenase-2 expression stimulated via LPS in BV2 cells (Chang et al. 2005). In another study, different plant extracts were prepared for screening in human peripheral neutrophils to determine the antagonistic activity via leukotriene B4 (LTB4) receptor. Results of the investigation illustrated that among the other plant extracts, the Semen armeniacae showed 70% antagonistic effects in overall experiment (Lee and Ryu 2000).

27.5.4 Hepatoprotective Effects

Studies have shown that apricots have significant hepatoprotective potential. In a study, 10% and 20% apricot-holding feed was testified against damage and hepatic steatosis induced by carbon tetrachloride (CCl_4) in Wistar male adult rats. The rats were divided into seven groups and were provided with 10% and 20% apricot-holding feed for 5 months. The group with CCl_4 treatment showed hazardous hepatic effects, including hepatic necrosis and vacuolated hepatocytes. Apricot-fed group showed remarkable retardation in liver injury as well as released the oxidative stress. The study attributed hepatoprotective effects of apricots to its antioxidant nutrients including β-carotene and vitamins and remarkable potential of radical-scavenging. Dietary intake of apricot can reduce the risk of liver steatosis and damage caused by free radicals (Ozturk et al. 2009).

27.5.5 Antinociceptive Effects

Apricot fruit as a whole contains numerous chemical entities that possess significant pharmacological and biological potentials. A compound amygdalin, also known as vitamin B_{17}, was first isolated from apricot kernels. This compound was investigated for antinociceptive activity through formalin induction of pain in experimental rat models. The criteria selected for nociception was shaking, biting, and licking, including the number of Fos-immunoreactive neurons in spinal cord and plantar skin expression of mRNA inflammatory cytokines. Results revealed significant paint reliving effects of amygdalin in a concentration-reliant manner. Moreover, the study reveals reduction of tumor necrosis factor-alpha (TNF-α) and interleukin-1 beta (IL-1β) activity (Hwang et al. 2008).

27.5.6 Enzyme Inhibition Potentials

Different studies were carried out in this context. A. study on five prunus species including *P. armeniaca* seed extract showed remarkable inhibition of plant proteinase trypsin. Inhibition of trypsin is vital for the defense mechanism of plants against predators and pests. The *P. armeniaca* extract revealed remarkable potency in enhancing the potential of plant defensive mechanisms (Gahloth and Sharma 2010). In another study, 38 different species of plants were collected from Kinki University, Japan, including 5 of prunus species. Results revealed strong suppressive effects of prunus species, including apricots against tyrosinase enzyme. This enzyme has a key role in melanin biosynthesis. Thus, the study concluded that these prunus species could prove beneficial for skin-whitening and hyperpigmentation (Matsuda et al. 1994).

27.5.7 Antimutagenic Effects

Ames/salmonella/microsome assay was implemented by Yamamoto et al. to determine the antimutagenic potency of Semen armeniacae. The mutagenicity of benzo [α]pyrene, 2-(2-furyl)-3-(5-nitro-2-furyl) acrylamide (AF-2), and 3-amino-1,4-dimethyl-5H-pyrido[4,3-b]indole (Trp-P-1), and 2-(2-furyl)-3-(5-nitro-2-furyl) acrylamide (AF-2) was significantly inhibited by the extract application of Semen armeniacae. The study attributed antimutagenic potency of Semen armeniacae extract to its chemical constituents mainly 0.7% w/w of oleic acid and 0.4% w/w of linoleic acid (Yamamoto et al. 1992).

27.6 Conclusion

Apricot is a very important fruit belonging to family Rosaceae. Apricot production varies from region to region within the globe with Turkey being the dominant producer of apricots with over 13 million tons annually followed by Iran with almost 7 million tons. Apricot is a delicious fruit with multiple and diverse uses amid large portion of global production preserved by drying. Apricots consist of balance of sugar, fibers, proteins, vitamins, minerals, acidity, and strong apricot aroma. Carbohydrates occur in range of 11–13% and are rich source of energy. Fresh fruits are excellent source of vitamin C and vitamin A. Apricots are highly enriched with essential minerals like potassium, phosphorous, magnesium, calcium, iron, and selenium, at the same time sodium, zinc, manganese, copper, and iron are also present in small amounts. Different parts of apricot have been reported with significant antioxidant activities which have been attributed to the presence of phytochemicals like fatty acids and sterols, polyphenols, sugars, volatile components, and cyanogenic glycosides.

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Kiwi

28

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Abstract

Since the past two decades, kiwi is one of the popular antioxidant fruits which has become widely sought due to its large production and various medicinal

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properties. *Actinidia deliciosa* ‘Hayward.’ Hayward is the most widely planted kiwifruit cultivar that possesses about half of kiwifruit cultivars globally. Kiwi being the sixth most valuable fruit crop after citrus, apple, pear, and peaches is traded internationally. It is a rich source of various antioxidants, including ascorbic acid, carotenoids, and phenolics. Kiwi being rich source of antioxidants helps in lowering the menace of chronic diseases such as heart disease, stroke, cancer, and diabetes and provides an alternative source of intervention in the aging process by protecting against oxidative damage by reactive oxygen species. The evidence from human intervention studies has proven that kiwifruit has a great contribution to improve digestive health to a huge extent as they are rich in actinide, a natural proteolytic enzyme which dissipates down the proteins and facilitates gastrointestinal disorders. Being one of the rich sources of bioactive compounds, kiwifruit also shows a wide diversity in size, shape, and flavor which has a deep impact on the expansion and export of fresh kiwifruit to a large extent throughout the world. Kiwifruit is also consumed and is accessible in processed forms, for instance, fortified drinks, candies, lyophilized products, dehydrated products, as well as juices.

Keywords

Kiwi · Antioxidants · Proteolytic enzyme · Health benefits · Cancer · Diabetes

28.1 Introduction

The most essential part of our daily routine and healthy diet is fruits as they usually contain low content of cholesterol, calories, sodium, and fat (Ciardiello et al. 2008). Besides this fruits are also rich in vitamins, enzymes, minerals, and fiber as well as antioxidant capacity. Fruits are abundantly rich source of various antioxidants, including ascorbic acid, carotenoids, and phenolics. Fruits are abundant sources of antioxidants, which lower the menace of chronic diseases including cancer, heart disease, stroke, and diabetes and provide an alternative source of intervention in the aging process by protecting damage against reactive oxygen species. As the antioxidants such as vitamin B, vitamin C (Ferguson and Huang 2007), polyphenols, vitamin E and carotenoids are present in less quantity in some fruits. One of the popular antioxidant fruits which has become widely sought since the past two decades due to its various productive and various medicinal properties is kiwifruit (Martin et al. 2013). The demand in regular consumption and in numerous health benefits of kiwifruit makes viable for consumption throughout the year (Vaughan and Geissler 2009).

Kiwifruit is a nutrient-dense fruit and is exceptionally high in vitamin C and other nutrients as well as significant levels of vitamin E, potassium, dietary fiber, and foliate as well as bioactive components. Besides this it provides a wide range of phytonutrients, antioxidants, and enzymes which are involved in the functional metabolic pathways of humans (Ferguson and Huang 2007). The evidence from human intervention studies has proven that kiwifruit has a great contribution to improve digestive health to a huge extent as they are rich in actinide, a natural proteolytic enzyme which segments protein and facilitates in the gastric digestion; besides this it stimulates the mobility of other phytochemicals (Richardson et al. 2018).

Kiwifruit, a wild species, was first exploited in China in the twentieth century. Owing to its primary health benefits, it became an essential commercial crop and got international economic significance (Ward and Courtney 2013; Ferguson and Bollard 1990).

There are about 76 species of genus *Actinidia* and 125 known taxa worldwide, and among these *Actinidia deliciosa* and *Actinidia chinensis* species are being produced commercially. The kiwifruit can be traced to the family of Actinidiaceae and genus *Actinidia*. The botanical name of kiwi is *Actinidia deliciosa* which was given in 1984. The name *Actinidia* is derived from the Greek word *Akinos* which means "ray" and was given to describe the radial appearance of the inside of the fruit. The word *deliciosa* comes from the Latin word *deliciosus* meaning "delicious" due to the juicy taste of kiwi (Richardson et al. 2018). The commercial cultivation species of kiwifruit are *Actinidia deliciosa* which has a considerably larger fruit size and productivity, low rate of respiration and ethylene sensitivity, and thus increased shelf life. The *Actinidia deliciosa* Hayward (fuzzy kiwifruit) species usually is a berry with an oval shape and has a dull brown color. Among the finest, most attractive features of kiwi is its remarkably beautiful appearance. The seeds of black color are sprinkled on the bright translucent green flesh in several rows. The flesh of green fuzzy kiwifruit provides a unique flavor combination of tangy, sweet, and sour. Besides the *Actinidia deliciosa* (species), there is another species known as SunGold (*Actinidia chinensis*); conventionally it has a bronze-colored skin, glistering yellow flesh enclosed by a smooth hairless skin, and a sweet and tropical taste (Richardson et al. 2018).

28.1.1 History

Kiwi being a wild species has come a long way from the temperate forests of southwest China. A lot of effort was done by various missionaries in the nineteenth century for the advancements in botany and distribution of horticultural plants. Jesuit priest Pere Pierre Noël Le Chéron d'Incarville sent the first botanical specimens of *Actinidia chinensis* to Europe in around 1750 and later it was sent by Robert Fortune. In 1845–1845 Robert Fortune, a co-worker from the Horticultural Society of London, was sent to China to collect the seeds of kiwifruit. The species was first considered as an ornamental plant only, having no edible part, and Fortune's specimen of *A. chinensis* was kept in London at the Royal Botanic Gardens. Currently New Zealand is a major producer of kiwifruit. After a visit from China, in 1904 a school teacher named Isabel Fraser returned and first introduced the seeds of kiwifruit in New Zealand (Ward and Courtney 2013). The large-scale plantings of commercial orchards occurred around the 1930s. There were no proven patterns of management by growers due to which they had to face many challenges in planting the kiwifruit (Ferguson and Bollard 1990). From the 1950s to the current scenario, the rapid geographical expansion of orchards began to develop throughout the globe, in New Zealand, Australia, Chile, the USA, Europe, and mainly in Italy, Greece, and France. In Italy kiwifruit is considered as being "frutto della salute" – the health fruit (Ferguson and Bollard 1990).

The kiwifruit now has switched on to a domestic fruit from being a wild plant as it has now achieved its importance in many countries. The name "kiwifruit" was suggested by Turners and Growers Ltd, which has been named after the flightless bird kiwi (which is the emblem of New Zealand), and the name kiwi by 1969 was well established and accepted (Ferguson and Bollard 1990). Though the kiwifruit season requires winter growing, the fruit can be stored favorably once harvested. It's produced in the southern hemisphere as well as the northern hemisphere which directly means kiwifruit is available throughout the year and fulfills the requirements (Richardson et al. 2018).

28.1.2 Production (India, World)

Actinidia deliciosa 'Hayward' is the widely planted kiwifruit cultivar as 90–95% of kiwifruit is being traded throughout the world (Guroo et al. 2017).

Kiwi, being the sixth most valuable fruit crop after citrus, apple, pear, and peaches, is traded internationally. The total production of Hayward is 1.8 M/T as it's one of the most essential commercial crops, and its total production is 1.8 M/T. About 2,500 farmers are associated with kiwifruit production in New Zealand as they harvest 3.7 billion kiwifruits/year (Belrose Inc 2007). The list of top kiwi-producing countries is shown in Table 28.1.

Kiwifruit is mainly being cultivated in the Bay of Plenty (North Island) in New Zealand. The brand name of kiwifruit is Zespri and is being marketed in about 55 countries which provide an ideal condition for plantation of kiwi; besides this, this area also receives enough sunlight and rainfall and there is no possibility of frost in spring. As Italy is one of the biggest producers of kiwifruit, it accounts for

Table 28.1 Countries that are leading producers of kiwifruit in 2013

Rank Country	Production (MT)
1 China	1,765,847
2 Italy	447,560
3 New Zealand	382,337
4 Chile	255,758
5 Greece	162,800
6 France	55,999
7 Turkey	41,635
8 Iran	31,603
9 Japan	29,225
10 United States	27,300
World	2,865,118

Source: Guroo et al. (2017)

about 3.5% of the total area in fruit crops and about 4% of total fruit production by weight. About 1.5–1.6 million (MT) of kiwifruits are produced each year (Guroo et al. 2017). One-third of kiwi fruit plantings are found in the southern hemisphere, and two-thirds of plantings are found in the northern hemisphere (Belrose Inc 2008).

India has significant production of the kiwifruit crop, particularly in the state of Arunachal Pradesh, which accounts for 56% (4800 tons) of India's total kiwi production. The largest kiwi producer in the country, Arunachal Pradesh, is followed by Nagaland (2400 tons), Mizoram (1030 tons), Himachal Pradesh (260 tons) and parts of Sikkim, Manipur, and Jammu Kashmir. However, the overall productivity of kiwi in Arunachal Pradesh is very low (1.2 mt/ha) in comparison to other states such as 12 mt/ha in Nagaland, 3.4 mt/ha in Mizoram, and 2.2 mt/ha in Himachal Pradesh. West Kameng, Tawang, and Ziro are the major production hubs of kiwi in the state (Guroo et al. 2017).

28.1.3 Botanical Description

Actinidia species are perennial, climbing plants where the vines with young shoots can grow to a height of more than 9 m and young shoots are covered with small hairs. Their leaves are usually long petioled and shaped non-uniformly and are colored and heart-shaped. Flowers appear approximately 60 days after bud bursts in spring. The flowers of both *A. deliciosa* (green kiwi) and *A. chinensis* (yellow kiwi) have creamish petals and which with age turn yellow and the kiwi plant of both the species bears only flower of one sex either female or male. The creamy flowers have a diameter up to 5 cm and they have five petals and sepals as well as has numerous stamens, and the stigma is positioned radially.

The species *A. deliciosa* (green kiwi) and *A. chinensis* (yellow kiwi) are very similar, as they are usually egg shaped and have many seeds embedded in the flesh and as they also vary in size, shape, pattern of hair, and internal and external color. The flesh of *A. deliciosa* has bright green color around a white core with fine pale lines radiating from it, whereas *A. chinensis* almost has smooth skin and almost hairless. The taste of this fruit is much sweeter than *A. deliciosa* and has more aromatic flavor (Ferguson 1999).

28.2 Antioxidant Properties

28.2.1 Fruit

Kiwifruit is one of the most important and nutrient-dense fruits, and extensive research has been done over the last decade on its health benefits on its regular consumption. The consumption of kiwifruit not only improves digestive system but also immune and metabolic health (Boeing et al. 2012). Kiwi being a wild species has come a long way from the temperate mountains and hills of southwest China. A lot of effort was done by various missionaries in the nineteenth century for the

Table 28.2 Proximate analysis of kiwifruit and ("green"and "gold" cultivars)

Proximate (per 100 g)	*A. deliciosa* green kiwifruit	*A. chinensis* gold kiwifruit
Water (g)	83.1	82.4
Energy (kcal)	61	63
Energy (kJ)	255	262
Protein (g)	1.14	1.02
Total lipid (fat) (g)	0.52	0.28
Ash (g)	0.61	0.47
Carbohydrate (g)	14.7	15.8
Dietary fiber (g)	3	1.4
Sugars (g)	9.0	12.3

Source: Richardson et al. (2018)

Table 28.3 Minerals in kiwifruit cultivars

Minerals (per 100 g)	*A. deliciosa* green kiwifruit	*A. chinensis* gold kiwifruit
Calcium (mg)	34	17.0
Iron (mg)	0.31	0.21
Magnesium (mg)	17	12.0
Phosphorus (mg)	34	25
Potassium (mg)	312	315
Sodium (mg)	3	3
Zinc (mg)	0.14	0.08
Copper (mg)	0.13	0.103
Manganese (mg)	0.098	0.05
Selenium (μg)	0.2	0.44

Source: Richardson et al. (2018)

advancements in botany and distribution of horticultural plants. Jesuit priest Père Pierre Noël Le Chéron d'Incarville sent the first botanical specimens of *Actinidia chinensis* to Europe in around 1750 and later it was sent by Robert Fortune. In 1845–1845 Robert Fortune, a co-worker from the Horticultural Society of London, was sent China to collect the seeds of kiwifruit (Ward and Courtney 2013). Fortune's specimen of *A. chinensis* was held at the Royal Botanic Gardens at Kew, London. This species was not considered an edible fruit but it was considered as ornamental plant. Currently New Zealand is a major producer of kiwifruit (Kaur et al. 2010). In 1904, Isabel Fraser, a school teacher, returned to New Zealand from China and introduced the kiwifruit along with its seeds (Ward and Courtney 2013). Kiwifruit is a rich source of vitamin C and large amount of nutrients with significant levels of potassium, dietary fiber, folate, and vitamin E, as well as various bioactive components, including a wide range of phytonutrients, antioxidants, and enzymes that are beneficial to metabolism of our body (Deng et al. 2016). Kiwifruit ("green" and "gold" cultivars) is consumed by removing the skin, and hence the proximate analysis of edible portion is shown in Tables 28.2, 28.3, and 28.4 (Sivakumaran and Sivakumaran 2017). With the increase in the consumer awareness and further

Table 28.4 Vitamin content of kiwifruit

Vitamins (per 100 g)	Green kiwifruit	Gold kiwifruit
Vitamin C (mg)	92.7	161.3
Vitamin B1 (mg)	0.027	<0.01
Vitamin B2 (mg)	0.025	0.074
Vitamin B3 (mg)	0.341	0.231
Vitamin B5 (mg)	0.183	0.12
Vitamin B6 (mg)	0.063	0.079
Vitamin B9 (μg)	DFE 25	31.0
Vitamin B12 (mg)	7.8	1.9
Vitamin A (μg)	0	0.08
Vitamin A (μg RAE)	4	1
Vitamin E (IU)	87	23
Vitamin K (mg)	1.46	1.51
Others (μg)	40.3	6.1
Beta-Carotene	52	14
Lutein + zeaxanthin	12	24

Source: Richardson et al. (2018)

scientific research, there is a huge demand of consumers who choose to eat this variety as it has increased the vitamin E, fiber, and folate contents by 32%, 50%, and 34%, respectively (Sivakumaran and Sivakumaran 2017; US Department of Agriculture 2016).

28.2.2 Juices

Kiwi juice is rich in antioxidants and micronutrients which have many beneficial effects on human health.The consumption of antioxidants present in fruit decreases oxidative DNA damage by H_2O_2 in humans (Collins et al. 2001).

28.2.3 Seed

Most of the fruits are rich source of antioxidants such as polyphenols as well as tannin content which gives its ability to scavenge free radicals. Tannins present in kiwi play a significant part as antioxidants in grape and apple fruit. The peels and seeds of various fruits are potential source of antioxidants (Deng et al. 2016).

28.2.4 Peel

Serotonin helps to promote better sleep and kiwi is rich in serotonin that prevents sleep disturbances, thus promoting better sleep (Motohashi 2002). A research conducted by Deng et al. (2016) showed that kiwi peels have the ability to scavenge free radicals and higher polyphenol concentration than the seeds. The peels and seeds of various fruits, which are waste products in fruit and vegetable industry, may be a potential source of antioxidants (Motohashi 2002).

28.2.5 Wastes

The volume of waste generated globally is estimated as 1.5 billion tons and its edible part is roughly 1.6 billion tons (Gustafsson et al. 2013). Food waste has substantial economic and environmental implications as it has negative impact on the environment. Wastes generated from the agricultural by-products are anonymously rich sources of phytochemicals, such as antioxidants and phenolics\compounds, anthocyanin, and flavonoids. The waste generated can be used as functional ingredients in animal feed, pharmaceutical, cosmetic, and food industries (Fontana et al. 2013). Little amount of scientific investigation has been performed in finding the application of kiwifruit pomace as well kiwifruit. Since the last 100 years, great effort has been done by fruit growers and processors to find application of kiwifruit waste such as apple pomace. There have been a number of researches published on kiwi which later on got its peak in 1992. Although there are just a few publications about the research done on waste and pomace processing, one of the first efforts utilizing kiwifruit initiated with producing kiwifruit juice which was then followed by kiwifruit vinegar. The production of vinegar from kiwifruit produced an excellent flavor. Kiwifruit vinegar ranks one of the most applications of kiwifruit wastes (Kennedy et al. 1999).

28.3 Antioxidant Properties of Kiwi Products

There are various processed products prepared from kiwifruit which mainly are juice concentrates, purees, and sliced or diced product. Some of the products that are prepared from kiwifruit are frozen, dehydrated, and lyophilized products along with candies, fortified drinks, purees, fruit drinks, yoghurts, confectionery, distilled spirits, etc.

Kiwi is considered as the source of antioxidants to combat cancer as by being cytotoxic to malignant cancer cells. It is probably found to decrease the chances of colon cancer as kiwi is rich in dietary fiber (Motohashi 2002). Kiwifruit helps to prevent the mutations of genes which may initiate the cancer process. One of the research hypotheses by Collins et al. (2001) has proven that kiwifruit decreases oxidative DNA damage in human cells induced by H_2O_2.

Since the last 100 years, great effort has been done by fruit growers and processors to find application of kiwifruit waste such as apple pomace. There have been a number of researches published on kiwi which later on got its peak in 1992. Although there are just a few publications about the research done on waste and pomace processing. One of first efforts to utilize kiwifruit initiates with producing kiwifruit juice which was then followed by kiwifruit vinegar. The production of vinegar from kiwi fruit produced an excellent flavor. Kiwifruit vinegar ranks one of the most application of kiwifruit wastes (Kennedy et al. 1999).

28.4 Characterization of the Chemical Compound(s) Responsible for Antioxidant Proprieties

Fruits species are largely appreciated and highly consumed throughout the world due its significant role as the fruits are natural therapeutical agents and their intake is prevention against the chronic diseases. Besides these properties of fruits, their peels, leaves, barks, roots, flowers, and leaves also possess medicinal properties. Fruits and vegetables are major source of vitamins and minerals, and in addition they are rich source of several bioactive compounds (mainly polyphenols) (Fujita et al. 2013; Kang et al. 2011; Zielinski et al. 2014; Singh et al. 2015). These are a rich source of bioactive compounds (polyphenols), having the ability to scavenge free radicals. The dietary fiber is present in sufficient quantities which in turn is very essential for intestinal health. The regular consumption of fruits is therefore recommended as it is a cure to some of the major chronic diseases like obesity, cardiovascular disease, cancer, and diabetes (Elleuch et al. 2011).

Kiwifruit contains a complex network of the antioxidants which are associated with physiological beneficial functions. The other antioxidants besides vitamin C and E include phenolics, including flavones and flavonones; the carotenoids zeaxanthin, lutein, and β-carotene; chlorophylls; quinic acid; caffeic acid; glucosyl derivatives; β-sitosterol; and chlorogenic acid. The role of antioxidant is to scavenge, delay, or retard the cell damage by free radicals that are generated by the normal metabolism of the human body (Latocha et al. 2010; Fiorentino et al. 2009; Park et al. 2006; Du et al. 2009).

28.4.1 Vitamins

There are several vitamins present in the fruits which boosts the immune system of human body and as well as reduces inflammation. The kiwifruit is a rich source of vitamins A, C, and E and B complex vitamins (Table 28.4) which are considered as antioxidants (Hakala et al. 2003). The quantity of vitamin C is mainly high in kiwifruit usually in both the commercial species of kiwi fruit (Drewnowski 2005, 2010; Darmon et al. 2005) which is almost more than three times the amount found in strawberries and oranges. Vitamin C is mainly involved in the proper metabolism of our body because of its wide range of biological functions. The enzymes that are vital for the biosynthesis of neurotransmitters, collagen, catecholamine, l-peptide, and carnitine is regulated by vitamin C (Englard and Seifter 1986; Arrigoni and De Tullio 2002). Vitamin C is also considered to boost the immune system of human body as they are responsible for defending the pathogens and thereby preventing the systematic infection (Vissers and Wilkie 2007; Parker et al. 2011). The high level of vitamin C has improved the bioavailability of vitamin C (Beck et al. 2010).

28.4.2 Minerals

Potential scientific research proves that minerals act as essential components for the human body in the development of bones and teeth. Minerals present in the kiwifruit help human body to balance electrolyte as well as play a role in metabolic catalysis, hormone functions, and binding oxygen in humans. Kiwi is also rich in minerals like potassium, phosphorus, magnesium, manganese, calcium, iron, copper, and sodium (Motohashi 2002).

28.4.3 Anthocyanins

Anthocyanins are also colored pigments that act as powerful antioxidants and widely distributed in fruits as well as vegetables. They are a subgroup of flavonoids that are commonly found in nature. These colored pigments have been associated with lower risk for certain chronic diseases such as urinary tract infection, cancers, improved memory, and normal aging (Zierau et al. 2002).

28.4.4 Polyphenol Components

The skin of kiwifruit is predominantly and richly concentrated with polyphenols. The pomace of the kiwifruit is the major source of polyphenols that consist of acid, epicatechin, and their oligomers, quercetin glycosides, and p-coumaric acid (Kennedy 1994). The other antioxidants besides vitamin C and E include phenolics, including flavones and flavonones, the carotenoids zeaxanthin, lutein, and β-carotene, chlorophylls, quinic acid, caffeic acid, glucosyl derivatives, β-sitosterol, and chlorogenic acid (Latocha et al. 2010).

28.5 Health Benefits

According to the food scientists and nutritionists, fruits and vegetables when consumed on daily basis contribute to reduce risks of certain diseases such as cancer and cardio- and cerebrovascular diseases (Liu et al. 2000). Consumption of kiwifruit has been found to prevent certain cancers and cardiovascular disease. Kiwifruit has been found to cure cancer, especially cancers of the lung, liver, and digestive system (Collins et al. 2003). As the antioxidants (polyphenol, ascorbic acid, carotenoids, and tocopherols) contribute these beneficial effects, these antioxidants scavenge the free radicals by reducing hydrogen peroxide, binding to metal ions, and quenching superoxide and singlet oxygen (Peschel et al. 2006). The potential property of kiwifruit is to lower the risk of cardiovascular disease (Gammon et al. 2012).

28.5.1 Digestive Health

Kiwi is a rich source of proteolytic enzyme actinidin, which improves the digestion of proteins present in the meal, and in turn it aids smooth traffic in the digestive system (Ferguson and Ferguson 2003).

28.5.2 Skin Health

Kiwi is a rich source of vitamin C as well as vitamin E, the most important antioxidants. These antioxidants helps to prevent damage caused by sun, pollution, and smoke and make the skin look young and vibrant and improve its texture by protecting it against degeneration. Besides this, kiwi is also a rich source of collagen, which is a protective protein that repairs the skin and helps to recover from cuts and wounds (Motohashi 2002).

28.5.3 Bone Health

Kiwifruit is a rich source of folate and magnesium and offers health benefits that range from bone formation. Vitamin K present in kiwifruit has a potential role in the bone mass building (Motohashi 2002).

28.5.4 Heart Health

The kiwi is rich in fiber and potassium which supports heart health. Fiber can reduce the risk of cholesterol, heart disease, and heart attack. A research showed that consumption of kiwi on a daily basis has reduced the risk of cardiovascular disease. Kiwifruit is an excellent source of omega-3 fatty acids which has reduced the risk of coronary heart disease and stroke to a huge extent (Motohashi 2002).

28.5.5 Hair Health

Kiwi is rich in omega-3 fatty acids and is rich in copper and iron which are highly nourishing for our body as they are responsible for improvement of hair growth and enhance blood circulation and also help to reduce hair fall by preventing hair from losing its moisture and graying (Motohashi 2002).

28.5.6 Eye Health/Macular Degeneration

Lutein “a carotenoid vitamin” can prevent age-related blindness. Our body can’t synthesize “lutein,” which is a phytochemical that is known to accumulate in the retina of the eye. It's therefore essential to get plenty of foods like kiwi that contains lutein (Motohashi 2002).

28.5.7 Clotting of Blood and Vitamin D Absorption

Vitamin K present in kiwifruit contributes toward normal functioning of nervous system, which includes clotting of blood and absorption of vitamin D (Darmon et al. 2005; Drewnowski 2010).

28.5.8 Physical Fitness

Kiwi contains lots of minerals and its consumption has been very helpful for keeping our body physically fit. Usually during exercise in summer season we lost lots of minerals that are essential in the metabolism of our body (Boeing et al. 2012).

28.5.9 Pregnant Women's Health

One of the most important and beneficial advantages of folate (vitamin B6) is that it aids in the development of the fetus and promotes its health. Kiwifruit being a rich source of vitamin B6 is considered one of the beneficial fruits for pregnant women (Boeing et al. 2012).

28.5.10 Better Sleep

Serotonin helps to promote better sleep, and kiwi is a rich source of serotonin that prevents sleep disturbances (Darmon et al. 2005; Drewnowski 2010; Motohashi 2002).

28.5.11 Depression

Kiwifruit contains an essential component "inositol" which contributes to reduce depression. Inositol works as a precursor of an intracellular second messenger system which can be a benefit in the treatment of depression (Tyagi et al. 2015).

28.5.12 Anemia

Kiwi is a rich source of iron which on its consumption helps to prevent anemia (Tyagi et al. 2015).

28.5.13 Cancer

Kiwi is considered as the source of antioxidants to combat cancer as by being cytotoxic to malignant cancer cells. It is probably found to decrease the chances of colon cancer as kiwi is rich in dietary fiber (Motohashi 2002). The mutation of genes which initiates the cancer process is prevented by consuming kiwifruit. One of the research hypotheses by Collins et al. (2001) has proven that kiwi fruit decreases oxidative DNA damage in human cells (Latocha et al. 2010; Fiorentino et al. 2009).

28.5.14 Diabetes

The low glycemic index of kiwifruit makes it appropriate for diabetic persons. Fruits such as the kiwifruit that are rich in fibers can prove beneficial for controlling blood sugar levels of patients with diabetes (Motohashi 2002; Fiorentino et al. 2009).

28.6 Conclusion

Fruit species are largely appreciated and highly consumed throughout the world due to its significant role as natural therapeutical agents and their intake is prevention against the chronic diseases. Beside these properties of fruits, their peels, leaves, barks, roots, flowers, and leaves also possess medicinal properties. Fruits are extensively and abundantly rich in minerals, vitamins, as well as antioxidant chemical properties. Vitamin C as well as E contributes to the normal psychological function of blood vessels, bones, skin, and nervous system. *Actinidia* species have been analyzed for their high antioxidant properties as well as vitamins C and E, thus highly ranked among highly notorious fruits.

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Litchi

29

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Abstract

A delicious fruit, *Litchi chinensis*, is commercially grown for food consumption and has numerous health benefits. Since it has numerous biological functions, this fruit has increasingly gained huge amount of popularity. Every part be its seed, pulp or coat equally is nutritionally important and valuable since it contains benefits like antioxidant, cancer disruptive and antimicrobial properties. This chapter helps to bring into limelight the structure, properties and nutritional values of the fruit along with numerous health benefits.

Keywords

Litchi · Antioxidant · Antimicrobial · Nutritional · Seed · Pulp

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29.1 Introduction

Litchi (Botonical name: *Litchi chinensis*), a medium-sized sub-tropical tree, belongs to the family *Sapindaceae*, and now they are being cultivated all over the world. The name generally refers to pink fruit which is shaped by this tree. It is native to Southern China. It accounts for about 85% of the world's population because of the geographical conditions of the country, but the overall yield is very low and quite unstable (Xu et al. 2010a, b). After China India stands second in production of litchi. It resembles various other edible tropical fruits like longan, rambutan and mamoncillo. It is also known as Chinese strawberry because of its origin from China and is closely related to strawberry. It consists of brown pericarp that surrounds a flesh (white in colour) known as aril which is quite famous for its amazing taste and functional properties (Jiang et al. 2013). In year 2012 litchi fruit has been included in the list of functional food as it contains adequate quantity of polyphenols, flavonoids, anthocyanins and polysaccharides that are enriched with antioxidant, anticancerous, antimicrobial and non-inflammatory properties (Duan et al. 2007a, b: Zhao et al. 2016). The pericarp of litchi, namely, FFP, that accounts for about 15% is discarded during the processing. The phenolic compounds present in LFP tissues were identified as procyanidin B2, epicatechin and procyanidin B4 (Duan 2007a). Litchi contains carbohydrates and fibres in higher amounts, while lipids and proteins are presented in limited amount. Although there are various cultivars of litchi in nature, majority of them have micronutrient content that includes vitamins like B complex, vit C, vit K and vit E; carotenoids; minerals like K, Cu, Fe, Mn, P, Ca, Na, Zn, M and Se; and various types of polyphenols that counteract the liver and weight problems (Table 29.1). Such types of micronutrients are fruitful for the blood and heart and help in prevention of various diseases like colds, flu, sore throat and fever and assist in the process of digestion.

Botanical Description:
Kingdom: Plantae
Order: Sapindales
Family: Sapindaceae
Subfamily: Sapindaceae
Genus: *Litchi*

Table 29.1 Micro- and macronutrients in litchi

Calorific value	66 kcal per 100 g
Water (measured in g per 100 g)	81.80
Vitamin C content (in mg per 100 g)	9.1 ± 3.7
Total polyphenol compound content (in micrograms/ gallic acid per 100 g)	180.0 ± 35.1
Total flavonoid content (in microgram/ quercetin per100 g)	52.8 ± 6.0
Protein content (measured in g per 100 g)	0.85
Total carotenoid content (in µg per100 g)	569.8 ± 118.1
Carbohydrate content (measured in g per 100 g)	16.55
Lipid content (measured in g per 100 g)	0.43
Dietary fibre content (measured in g per 100 g)	1.32

Species: *L. chinensis*
Vernacular name: *Nephelium litchi*

Litchi Tree The litchi tree is a dense, round shaped and slow growth tree with about 30 to 100-feet height and equally broad leaves. The leaves of the tree are 5 to 8 inches long having the pinnate of four to eight points. Leaflets are found to be glossy and dark green which seem to be very appealing to the eyes (FAO 2019).

Litchi chinensis is an evergreen tree with a greyish black bark and shiny leaves with deep green colour. The crown of the fruit is round shaped and dark red in colour. The flowers of the plant have the terminal type of inflorescence with a small whitish pulp rigid cover of which comes off easily. This fruit has an excellent flavour with a balanced combination of acids and sugars (Septembre-Malaterre et al. 2016).

Flowers The flowers of the tree are whitish green in colour which sometimes becomes yellow. These are found in clusters of 30 inches (75 cm) (FAO 2019).

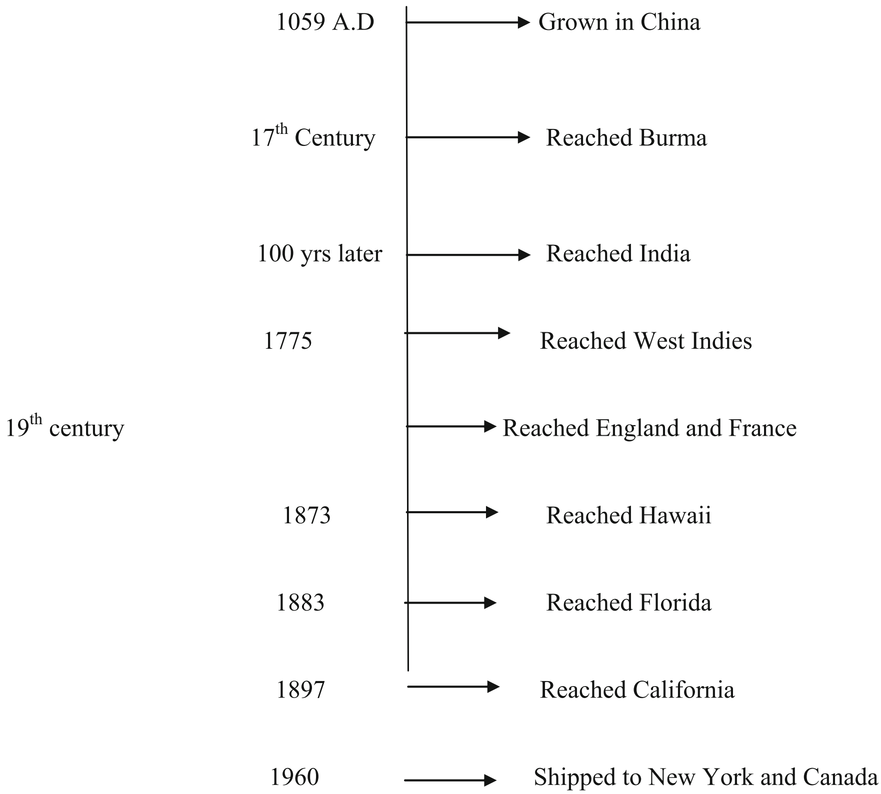
Fruits The fruits of the tree are extremely showy and ornamental and are usually found in pendant-type clusters of two to 30 fruits in each. Usually the colour of the fruit is either baby pink, light pinkish amber or at times strawberry red in appearance. They are round, heart shaped and oval in shape. The size of the fruit is about 1 inch wide and 2 inches long. As far as the outer appearance of the fruit is concerned, it is rough and hard in texture, but the outer covering is easy to remove if the fruit is fresh. Below the rough and hard texture of the outer skin of the fruit lies a crystal white flesh of the fruit which is extremely glossy, thick and tender upon consumption. The taste of the fruit is neutral and unique. This fresh and soft flesh is easily separated from the skin once pressed or pushed hard or upon consumption. The seed comes out clean with no sticky residues around it (Soni and Agrawal 2017). The seed of the fruit is oblongated usually 20 millimetres long and has a dark brown shiny coating around it. If the seed is broken it turns out be white in colour from the inner side. Sometimes because of an error in pollination the flesh content increases resulting in shrunken and dehydrated seeds; these types of fruits are usually prized because of their high flesh content and bigger size (Morton 1987). There are generally three varieties of fruit: normal, aborted and seedless. In the normal variety, the fruit has a dark brown-coloured seed with a live embryo with a fully mature and a well-developed aril. In the aborted variety the fruit has a well-developed aril which fills the entire area provided by the pericarp. The seed of this variety is small and shrunken with an open cavity and a dead embryo. As per Huang (2005), this phenomenon is botanically called as stenospermocarpy. In the seedless fruit variety, parthenocarpic, the ovary is not fertilised.

There are a large number of health benefits that are associated with the litchi fruit which not only include antioxidants but also anticancerous properties including large number of antimicrobial, anti-inflammatory and a number of other properties. Therefore, keeping in view the large number of health benefits, litchi is considered to be among one of the finest functional foods with a large number of bioactive components. Apart from the large number of health benefits, this fruit has a huge commercial acceptability not only in the form of processed juices and jellies but also in the dyeing industry where discarded fruit peels are a great source of providing dyeing colour and also act as a potential green inhibitor in the mild steel industry (Ramananda Singh et al. 2015).

29.1.1 History of Litchi Crop

The history of litchi dates back to China in 1059 AD when the growth of this fruit was flourishing in island and on the shores especially around rivers in Southern China. The lowland litchi that is present in China is a result of litchi trees being washed off by water and the seed being transported by birds to various other parts of other mountains were the growth of wild litchi is flourishing. Even till date there are certain villages in China that have litchi trees dating back to hundreds of years which provides a clear evidence that some of its basis are also lying in areas that are in and around Vietnam. Guangdong is called as the kingdom of litchi as the largest production of litchi is in this area in China. It contains grooves that date their production back to 2000 years. It was from there that various historians, travellers and tourists brought this fruit to various places of the world where the growth of the fruit is currently flourishing.

29.1.2 Timeline of Litchi Distribution in the World



29.2 Antioxidant Property of Litchi Pulp, Peel, Seed, Waste and Its Products

Antioxidants are substances which delay or inhibit the oxidative changes by scavenging the free radicals. Free radicals are responsible for oxidative stress in cell causing large number of health issues which include cardiovascular diseases, ageing, cancer, etc. Antioxidants have the property to act as free radical scavengers and help protect biological systems from oxidative damage and chain reactions and lower the risk of numerous chronic diseases (Li et al. 2015).

Litchi is enriched with phenolic compounds which aids in improving anti-influenza actions, blood circulation, weight reduction and prevention of skin from harmful UV rays of the sun. Oligonol is rich in polyphenol that is used for conversion of higher molecular weight proanthocyanidins into lower-molecular compounds that improve bioavailability (Aruoma et al. 2006: Park et al. 2015.).

Oligonol has significant effects on various types of chronic diseases (Choi et al. 2016: Fujii et al. 2008). It has tremendous effect on diabetes-related body disorders, kidney disorder-mediated oxidative stress and inflammation, mostly in type 2 diabetes. However, it has been reported that oligonol has shown positive effects on phorbol-induced tumour, and the expression of COX-2 has been successfully reported in mouse skin which has in turn reduced DNA binding (Kundu et al. 2009). Oligonol has shown beneficial effects in inhibiting melanoma-derived lung metastasis in mice (Lee et al. 2009). It has also been reported that oligonol helps in the production of inflammatory mediators and suppressors like NF-κB and ERK in majority of HepG2 cells and in vivo models.

Litchi fruit consists of about 82% water, 72% carbohydrate, 1% protein and negligible amount of fat (Emanuele et al. 2017). Litchi fruit is rich in nutraceutical fundamental compounds. This beneficial effect is associated with high content of micronutrients like vitamins such as B complex precursors like carotenoids; minerals like potassium, copper , iron and magnesium; and also polyphenols (Table 29.2) (Septembre-Malaterre et al. 2016). Hence litchi fruit has been used in making various healthy foods like beverages, drinks, soups, etc.

The colour of litchi fruit is a result of anthocyanin pigment present in the fruit skin (Prasad and Jha 1978). These are cyanidin-3-glucoside, cyanidin-3-rutinoside and malvidin-3-glucoside. Colour is the important indicator of ripeness and postharvest life of the litchi fruit. Colour change during ripening is due to the unmasking of anthocyanin pigments and degradation of chlorophyll pigments in the fruit pericarp (Nagar 1994). The principle agents responsible for this degradation are pH changes (due to leakage of organic acids from the vacuole), oxidative systems and enzyme chlorophyllases. These anthocyanin pigments present in fruit pericarp have potent antioxidant properties. Duan et al. (2007a, b) have found anthocyanins from litchi pericarp to inhibit linoleic acid-based oxidation and exhibit a content (dose)-dependent free radical scavenging activity against DPPH radical, hydroxyl radical and superoxide anions. Litchi as a whole fruit is composed of good quantity of antioxidants. Antioxidant property of litchi extract is associated with the presence

Table 29.2 Composition of 100 g of litchi fruit as per USFDA

S. no.		Amount
1	Sugar	16.5 g
2	Energy	66 calories
3	Protein	0.83 g
4	Fat	0.44
5	Ash	0.44 g
6	Edible fibre	1.3 g
7	Calcium	5 mg
8	Iron	0.31 mg
9	Zinc	0.07 mg
10	Thiamine	0.011 mg
11	Riboflavin	0.065 mg
12	Niacin	0.603 mg
13	Pyridoxine	0.1 mg
14	Folate	0.014 mg
15	Vitamin E	0.07 mg
16	Tryptophane	0.007 mg
17	Lysine	0.041 mg
18	Methionine	0.00gmg

Emanuele et al. (2017)

of flavonoids, polysaccharides, tannins, etc. Concentration and composition of phenolics of litchi is affected by genetic, agricultural and ecological factors. Difference in concentration of phenolic content and antioxidant activity is among fruit species and even the cultivars of same species (Emanuele et al. 2017).The antioxidants present in fruit are of great interest as potential protective agents against oxidative damage to DNA which results in cancer, heart ailments and other old age health issues. Not only the pulp which is edible portion of the fruit but also the peel and seeds are enriched with antioxidants (Zhu et al. 2019); a large quantity of flavonoids are found in litchi seed and pericarp part, and these are the by-products which are discarded and not utilised. Utilisation of these by-products can be done for flavonoid compounds. Flavan nucleus possesses low molecular weight plant phenolic compounds called as flavonoids. Flavonoids present in fruit are produced by plant as secondary metabolites, which are important for plant as they act as stress-resistant agents. These flavonoids show antioxidant activity, free radical scavenging and metal chelating activity. Hence they chelate redox-active metals, inhibit lipid peroxidation and affect other processes involving reactive oxygen species. Flavonoids also show various physiological activities such as cardiovascular benefits, hypertension reduction, anti-osteoporosis, anti-inflammatory, antihepatotoxic and anti-ulcerative (Yao et al. 2004). Hence they are beneficial to human health.

29.2.1 Pulp

This fruit has a whitish pulp with fruity smell and pleasant fragrance. It is found that litchi pulp consists of large amount of bioactive polysaccharide compounds like arabinose, mannose, galactose, and xylose which has antitumour activity including hepatocarcinomic and adenocarcinomic effect (Emanuele et al. 2017). Litchi polysaccharides exhibit strong antioxidant properties. Kong et al. (2010) used in vitro method to reveal antioxidant properties of litchi pulp. Water-soluble polysaccharides were first isolated from pulp and then purified. It was found that a fraction of pulp composed of polysaccharide surrounded with protein and composed of rhamnose, arabinose, galactose and glucose has the highest antioxidant activity. Dried pulp is shown to have better stimulatory effect than fresh pulp. Bioactivity of polysaccharides is enhanced by drying litchi pulp. Litchi pulp is also rich in phenolic compounds such as gallic acid, (−)-epicatechin, chlorogenic acid, caffeic acid, (+)-catechin and rutin which has good antioxidant properties (Zhang et al. 2013). HPLC analysis has revealed that quercetin 3-rut-7-rha, rutin and epicatechin are the major compounds having antioxidant properties (Su et al. 2014a, b). Epicatechin and cathechin were found to be in higher content with amount of 442.04 and 327.83 83 μg/100 g, respectively, in litchi pulp. Saxena et al. (2011) have studied the antioxidant and radioprotective effect of litchi pulp. They found that Indian litchi cultivars 'Shahi' and 'China' were found to be good sources of antioxidants and possessed strong radioactive protection compound ability, as evidenced by the considerable protection towards the pBR322 plasmid DNA, even at a dose of 5 kGy. Litchi fruit contains both free and bound phenolic compounds (Su et al. 2014a, b). Bound phenolics are those which have formed covalent bonds with the polysaccharides, proteins or lipids and also these phenolic compounds have hydrophobic interactions which affect their release from source and also their bioavailibity in GI tract. About 4–57% of the total phenolic compounds present in fruits existed in their tightly bound forms (Chu et al. 2002). These bound phenolics cannot be extracted from matrices into water or aqueous/organic solvent mixtures. These bound phenolics can be extracted using alkaline, acidic or enzymatic hydrolysis. Zhang et al. (2013) used alkaline hydrolysis for the release of bound phenolics from litchi fruit, while Bonoli et al. (2004) found that acid hydrolysis is more effective for the release of tightly bound phenolics than alkaline hydrolysis.Antioxidant play protective role in our bodies. They protect our body from the oxidative stress caused by free radical damage. Free radicals adversely affect the lipids, proteins and DNA and thus are responsible for a number of human diseases. Antioxidants work as free radical scavengers by not allowing and correcting damages caused by free radicals. These studies show that litchi pulp is a good source of antioxidants and thus has positive effect on human health. Hence dietary consumption of this fruit may be beneficial. Excessive eating of litchi causes heating symptoms such as sore and swells in the throat; boils in the mouth, tongue and face; etc. Huang and Wu (2002) found that heating of foods such as litchi when induced in vitro causes proinflammation reactions, while cooling foods like bitter melon did not show such reactions. This heating effect may be due to the inflammation reaction in nature.

29.2.2 Pericarp

Pericarp constitutes about 15% of the total fruit. Pericarp of fruit which is mostly inedible consists of large proportion of bioactive compounds and mainly consists of flavonoids and anthocyanins. Major anthocyanins present in fruit pericarp are cyanidin-3-glucoside, cyanidin-3-rutinoside, quercetin-3-rutinoside and quercetin-3-glucoside, and the major flavonoids are proanthocyanidin B2, proanthocyanidin B4 and epicatechin. Structure of major flavonoids is given in Fig. 29.1. Pericarp of fruit represents good antioxidant properties because of bioactive compounds present in it like dehydrodiepicatechin, proanthocyanidin, 7-O-(2,6-O-α-L-rhamnopyranosyl)-β-D-glucopyranoside, proanthocyanidin, 8-(2-pyrrolidinone-5-yl)- (−)-epicatechin, (−)-epicatechin D-glucopyranoside, naringenin and rutin. Various phenolic compounds present in litchi pericarp and their percentage are given in Table 29.3. Das et al. (2016) evaluated and compared the antioxidant efficacy of litchi pericarp extract with the synthetic antioxidant BHT (butylated hydroxytoluene) in sheep meat nuggets. 10 mg of litchi fruit extract was compared with the 100 ppm of BHT, and it was found that 15 mg concentration of litchi fruit extract has higher phenolic content and reducing power than synthetic. In addition

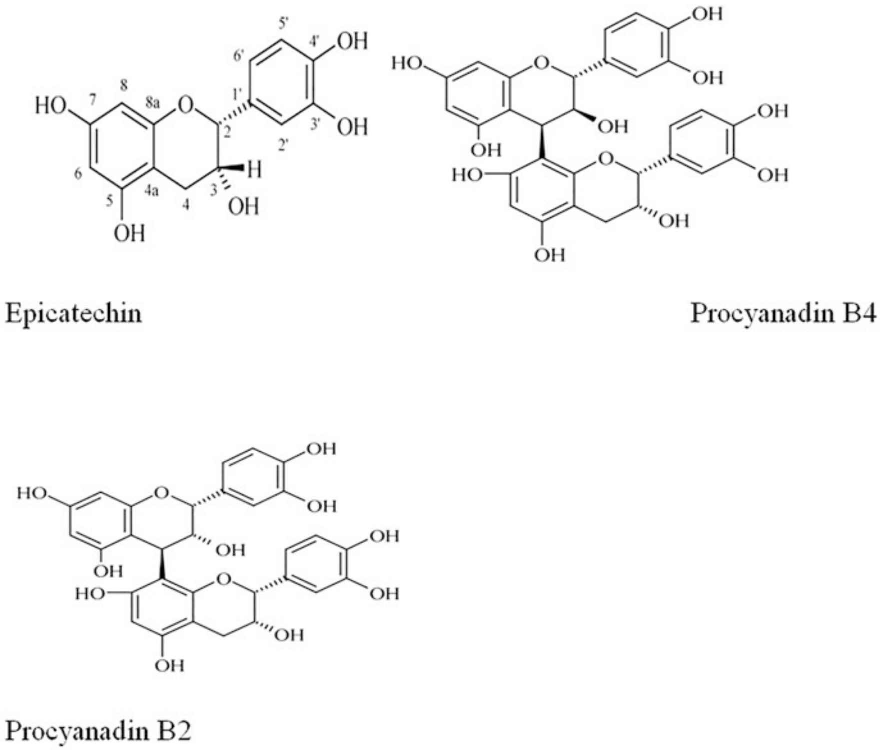


Fig. 29.1 Structure of major flavonoids. (Source: Duan et al. 2007a, b)

Table 29.3 Various phenolic compounds present in litchi pericarp

S.no	Phenolic compound	Percentage
1	(−)-Epicatechin	31.3
2	Cyanidin-3-glucoside	32.3
3	Procyanidin B2 content	10.3
4	(−)-Epigallocatechin content	11.2
5	Procyanidin B4 content	5.2
6	(+)-Catechin content	1.6
7	Gallocatechin content	1.3
8	Procyanidin B1 content	1.3
9	Gallic acid content	0.6
10	(−)-Epicatechin-3-gallate content	0.4

Source: Li and Jiang (2007)

litchi skin is also used traditionally to prevent heat treatment effect from taking the flesh of fruit, but the mechanism of cooling effect of litchi skin is unknown (Wang et al. 2008). Mature litchi skin also contains some polysaccharides which exhibit antioxidant activity. Yang et al. (2006) used anion-exchange column in combination with Sephadex G-50 gel permeation column to polysaccharides from mature litchi skin. These polysaccharides mainly consist of 65.6% mannose, 1.4% arabinose and 33.0% galactose. Gao et al. (2017) found that polysaccharides from the litchi pericarp exhibit strong antioxidant activity.

During ripening of litchi fruit, there occur changes in chemical composition of fruit including phenolic compounds also. It has been found that antioxidant properties of pericarp vary during different maturity stages of fruit. Zhang et al. (2013) found that the antioxidant activity of skin of immature fruit is much greater than of mature fruit. Quantity and quality of antioxidants present in fruit also vary in different cultivars and thus differ in their antioxidant properties.

29.2.3 Seeds

Litchi seeds or the endocarp of fruit is also the inedible portion of fruit. These seeds are used for medicinal purpose in China as pain reliever (Emanuele et al. 2017). Litchi extract can also be used for intonation of blood glucose and lowering the levels of blood lipids (Li and Jiang 2007) Litchi seed extract is rich in polyphenols mainly as flavonoids and condensed tannins. Xu et al. (2010a, b) found that same components were present in the seed as found in the pericarp of the fruit by reverse-phase HPLC. These compounds are gallic acid, (−)-gallocatechin, procyanidin B2, (−)- epicatechin and (−)-epicatechin gallate. The presence of these compounds shows that litchi seed extract can be used as source of antioxidants. Litchi seeds are found to be toxic to humans. These seeds are found to be toxic because of the high presence of methylene cyclopropyl acetic acid (MCPA) and other toxins like (MCPG). They are responsible for hypoglycaemic encephalopathy (Emanuele et al. 2017). It is the problem caused by the lack of glucose availability to the brain cells.

Recent outbreak of acute hypoglcaemic encephalopathy occurs in Muzaffarpur, Bihar, India (Shrivastava et al. 2017). Mostly undernourished children were affected by this neurological illness. The reason behind this was found to be the toxins present in litchi seed. Undernourished children develop hypoglycaemia because of less or no food intake. The brain needs normal level of glucose to work and the liver of these undernourished children is unable to do so. The alternate pathway for glucose synthesis then becomes fatty acid metabolism which is blocked by toxins present in litchi seed.

29.3 Health Benefits

The litchi fruit has been used as a healthy alternative over regular allopathic medicine since a very long time in many areas especially China because of the presence of numerous healthy nutrients. This fruit has numerous health benefits which include cure for loose motions, skin disorders, reduction in stomach pains and a beneficial compound for the heart, brain and liver.

29.3.1 Supports Digestion

It is highly enriched with dietary fibre that behaves as a laxative and helps in easy bowel movement. Peristaltic movement in the small intestine is facilitated by fibre that helps in easy movement of food. The stimulation of gastric and other enzymatic juices is secreted efficiently which helps in sufficient nutrient absorption. Majority of gastrointestinal disorders are lowered.

29.3.2 Enhances Immunity

Litchi is a rich source of vitamin C. In single serving, it provides almost 99% of vitamin C requirement. Vitamin C which acts as antioxidant boosts the immune system which promotes the functionality of WBCs that helps to enhance the immunity of the body.

29.3.3 Prevents Cancer

Litchi contains proanthocyanidins and polyphenolic compounds that help in eliminating the free radical formation and in preventing the body from various diseases. Free radicals are the dangerous by-products of the cellular metabolism that could lead to cardiovascular, carcinogenic, premature ageing and other cognitive diseases. About 52–101 g/kg DW of phenolic compounds has been identified in the pericarp of litchi that exhibits bioactivities like FRAP and strong activities of DPPH scavenging and oxidative DNA damage protection (Wang et al. 2008). There are huge amounts of organic compounds that reduce the risk of cancer in the human body which include tannins, anthocyanidin, etc. (Sarni-Manchado et al. 2000).

29.3.4 Hepatoprotective Activity

The chloroform and methanol allied compounds present in litchi leaf help in reduction of paracetamol-induced damage to human body especially the liver (Basu et al. 2012). Litchi leaves have significant effect on various serum-based compounds like serum SGOT, SGPT and SALP. Also compounds like protein, cholesterol, bilirubin and triglycerides are hugely affected by litchi

29.3.5 Anti-inflammatory Effect

Flavanol (flavan-3-ol) an important flavonoid present in rich litchi fruit extract (FRLFE) is composed of oligomerised polyphenol rich in dimer, flavanol monomers and trimers. The presence of such functional food has reportedly shown to reduce the inflammation and damage of the tissues resulting from high-intensity exercise training. FRLFE causes degradation of mRNA and expression of proteins belonging to iNOS gene, leading to the inhibition of IL-1b-induced NO production. FRLFE is also responsible for suppression of the phosphorylation of NF-kB inhibitor a (IkB-a) and reduced the mRNA levels of NF-kB in target gene, TNF-a (Yamanishi et al. 2014).

29.3.6 Antiviral Properties and Circulation of Blood

Proanthocyanidins and litchitannin A2 present in litchi fruit possess antiviral properties that help in reduction of the growth of viruses such as coxsackie virus and herpes simplex virus. Copper and iron present in litchi is essential for the formation of red blood cells. Copper promotes the enhancement of blood circulation and increases the oxygenation of the cells and organs.

29.3.7 Maintains Blood Pressure

Lychee Litchi that contains a good source of minerals like potassium helps in maintaining the balance of fluid present in the body. The balance of fluid assists in the regular metabolic functions and hypertension disorders. Potassium that acts as a vasodilator helps in lowering the constriction of blood vessels, arteries and blood vessels. Stress related to cardiovascular system has also been lowered by the presence of this vitamin. Potassium is three times present in dried litchi compared to the fresh litchi.

29.4 Conclusion

Litchi fruit contains numerous bioactive compounds that help to prevent a number of health issues like cancer, tumour-inducing cells, etc. therefore isolation of the same compounds and using them in separate combinations can help to develop an effective preventive measure against these diseases. Therefore, complete knowledge of this fruit variety and its biological mechanisms is extremely recommended to produce new variety of bioactive compound for improved human health.

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Loquat

30

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Abstract

Loquat is considered to be a delicious wonder summer fruit because of its varied advantages. Being rich in various nutrients, it has good medicinal value. In most cases, the whole plant including the peel, flower, seeds followed by leaves is used. The biochemical activity of the fruit possesses antioxidative, anti-nitrosaminic, anticancerous, antimutagenic, and anti-peroxidant effect. Not only proteins, carbohydrates, and fats are present in rich amounts but also higher concentration of various vitamins and minerals is also found. Utilization of loquat as a traditional medicinal plant in curing many ailments like gastrointestinal, respiratory, heart, as well as urinary diseases provides insightful loads toward its utilization in food and pharmaceutical industries.

Keywords

Loquat · Phytochemicals · Triterpenes · Anticancerous · Antimutagenic · Caffeic acid

30.1 Introduction

30.1.1 History

Loquat (*Eriobotrya japonica* Lindl.) (syn. *Mespilus japonicus* Thunb.) is a small evergreen fruit tree having rounded crown with short trunk that belongs to the family Rosaceae, subfamily Pomaceae (Hong et al. 2008). The fruit is also known by other names based on the country's origin as Japanese plum, Japanese medlar (biwa), or

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Table 30.1 Common and scientific names of loquat that are available with different native states

Scientific name	Prevalent name	Native region
E. bengalensis Hook.f.	Bengal Loquat	South Asia
Forma intermedia Vidal	Intermediate Bengal Loquat	Bengal
E. bengalensis Hook. f. *forma angustifolia* Vidal, *E. malipoensis* Kuan, *E. obovata,* and *E. henryi* Nakai	Narrowleaf Bengal, Malipo Loquat, Obovate and Henry Loquat	Yunnan, China
E. cavaleriei Rehd	Bigflow Loquat	Sichuan, China
E. deflexa Nakai, var. *buisanensis* and var. *koshunensis* Nakai	Taiwan Loquat, Wuweishan Loquat, and Kokshun Loquat	Taiwan, China
E. elliptica Lindl. and E. *hookeriana* Decne	Tibet and Hookiana Loquat	Tibet, China
E. fragrans Champ	Fragrant Loquat	Guangdong, China
E. japonica Lindl., *E. prinoides* var. *dadunensis*	Loquat, Oakleaf, Daduhe Loquat	Sichuan, China
E. salwinensis, E. seguinii Card, and *E. serrate* Vidal	Salwin, Seguin, and Serrata Loquat	Yunnan, China
E. tengyuehensis	Tengyue Loquat	Yunnan, China
E. kwangxinesis Chun (kw)	–	Guangxi, China,
E. stipularis Craib	–	Cambodia

Source: Yang et al. (2005) and Lin (2003)

Maltese plum, bibassier (French), nespola del Giappone (Italy), Japanische mispel (Germany), ameixe do Japao (Portuguese), nispero Japones (Spain), malta engi/ Maltese plum (Turkey), loquat (USA and India), and pipa or luju in China. Internationally it is named as loquat (Lin 2017; Morton 1987). *Eriobotrya japonica* is a Greek word where "erion" means wool and *japonica* refers to Japan (Akhtar et al. 2010). Thunberg first found it in 1822 in Japan. This Greek translation of *Eriobotrya* "woolly inflorescence" well depicts the extremely hairy condition of buds, flowers, fruits, and leaves. In China it is called as "rush orange" (Smock 1937; Cuevas et al. 2003). Earlier there used to be more than 500 different cultivars of loquat that were identified from China, most of which are from seedling selection and are not made available for production. These cultivars were well-kept in Fuzhou in the National Fruit Germplasm Repository (Badenes et al. 2013). Nowadays there are more than 20 (and less than 50) different varieties of loquat that are available with different native states as shown in Table 30.1.

Among the above cited cultivars, *E. japonica* is the only one cultivated for its fruit and strong disease resistance (Li et al. 2011), whereas *E. deflexa* and *E. prinoides* are used as rootstocks, and *E. cavaleriei* (having tiny fruit) is used to make wine especially in China. Currently the genus includes approximately 14 species in China (Zheng 2007). The most productive cultivars in Adana were the Baffico, Champagne de Grasse, and M. Marie, whereas largest fruits were obtained from

Ottawianni and Gold Nugget. The highest seed to flesh ratio and the lowest number of seeds per fruit were determined in Tanaka (Polat 2018). The fruit is generally having high market value because of its shorter fresh seasonal availability. Currently there is a wider cultivation of the fruit in more than 20 countries (comprising Japan, China, Australia, Brazil, India, Italy, Turkey, Israel, the USA, and Spain) (Tian et al. 2011).

30.1.2 Production

30.1.2.1 India

In India, the fruit is commercially cultivated under subtropical conditions in the states of Punjab, Uttar Pradesh, Assam, Delhi, Himachal Pradesh, and Maharashtra. Here the fruit is generally known by the name as Lukat or Lugath. In Pakistan, two different cultivars Surkh and Sufaid (local) and Tanaka are grown. Local cultivar is also widely cultivated in Punjab. Tanaka is considered to be the exotic group that was introduced in the year 1965 (Caballero and Fernandez 2003). In North India loquat fruit ripens during the end of March till May, at the time when there are only few fresh fruits available in the market.

30.1.2.2 World

Loquat cultivation has been distinguished because of its prominent organoleptic attributes, nutraceutical properties, and reduced phytosanitary problems (Pio et al. 2008). The onset of the spring festival generally starts with the ripening of the fruit in southeast parts of China, and fruit is extremely popular for more than 2000 years. The growth rate was about 1,200,000 tonnes in 2010 with about 170,000 ha of cultivation area. Spain remains the chief exporting country (Janick et al. 2015) and produced around 40,000 tonnes from about 3000 ha. Turkey is also considered as an important producer of loquat in the world with an approximate production of 12,310 tonnes in 2006 (Polat 2007). Brazil and the Western Mediterranean region of Turkey have the most prominent ecological conditions for the growth of loquat. The maximum production of approximately around 58.2% was from the Antalya region of the West Mediterranean region (Ercisli et al. 2012). In 2008, 157,190 loquat trees were planted of which 132,960 were bearing, in the West Mediterranean region with a growth number of 7347 tonnes (Celikyurt et al. 2011). The cultivar of fruit was brought to the USA in the eighteenth century and is also grown in other areas of South Africa, South America, Australia, and California (Crane and Caldeira 2006). There are mainly eight different varieties grown in the Lebanon region of with the common names given by the farmers are Ahmar, Baladi, Saidaoui, Espani, Faransi, Turki, Argelino Jin, etc. (Chalak et al. 2014; Talhouk et al. 2008). Presently, the fruit is cultivated in more than 30 countries worldwide (Zhou et al. 2007). Table 30.2 shows a comparative study of the increased production of loquat in terms of area and production from 2003 to 2007.

Table. 30.2 Area per hectare production of loquat in the year 2003 and 2007

Countries	Area (ha) 2003	Production (t) 2003	Area (1000 t) 2007	Production (t) 2007
China	42,000	200,000	118.27	453.6
Spain	2914	41,487	3.023	43.30
Turkey	1470	13,500	0.82	12,310
Pakistan	10,000	12,800	1.38	–
Japan	2420	10,245	2.42	10.24
Morocco	385	6400	0.38	4.41
Italy	663	4412	0.66	4.41
Israel	330	3000	0.33	3.00
Greece	300	2750	0.3	2.75
Brazil	300	2400	0.3	2.40
Portugal	243	950	0.24	0.30
Egypt	33	440	122.08 ha	1273
Chile	138	–	0.14	0.30
Total	62,196	314,384	131.26	549.22

Source: Elasbagh (2011) and Lin et al. (2007)

30.1.3 Botanical Description

30.1.3.1 Fruit Physiology and Biochemistry

By nature loquat is non-climacteric as there is no broad response to ethopen to elevate fruit ripening, but few cultivars have a fading pattern alike to that of climacteric fruits. The trees are evergreen, spreading, and erect growing. A fully grown tree may attain a height of 7–8 meters (20–3- feet) and have a rounded to upright canopy. Leaves are usually elliptical-lineolate to obovate-lanceolate, 5–12 inches elongated, and 3–4 inches broad with dentate margins (Agricultural Ministry, NIPHM 2015). The leaves are dark green and shiny on the dominant surface and whitish to rusty-to-mentose from the inferior side (Jonathan et al. 2006). The flowering season is autumn or early winter and the fruits will ripen in late winter or primal spring, i.e., from December to July. Ripening of fruit is a genetically programmed process involving changes in concrete and biochemical processes like change in skin cast, flesh texture, TSS, acidity, and unsteady compounds (flavor and aroma compounds) and chemical compounds as well, which makes the fruit fit for fresh consumption (Amoros et al. 2003). The quality of loquats is highly contingent on the ripening stage at the time of harvest. During ripening chlorogenic concentration rises from 13.7% to 52.0% that contributes to the rise on total phenolic concentration (Pareek et al. 2014). Around 78 different volatile compounds were found in fresh loquat fruit. Among these, 15 compounds significantly volunteer to the aroma of which the absolute potent is phenylacetaldehyde. Additionally, other aroma compounds like hexanal, (E)-2-hexenal, hexanoic acid, and β-ionone are also valuable (Takahashi et al. 2000).

Flowers are propagated on 10–20 cm-long terminal panicles of 30–100 or more flowers. Individually flowers are 1.25–2 cm elongated with five white petals, five sepals, about 20 stamens, an inferior ovary (five celled with 20 ovules), and five pistils joined at the base (Lin et al. 1999). The fruits are being chosen with respect to certain external characteristics such as shape, color, dimension, and without skin defects (Canete et al. 2007). The fruit is often compared to apricot due to its similar size, taste, and texture and to apples because of its high sugar, acid, and pectin content (Anonymous 2006). The flesh color differs from orange to light cream. The fruit is pome with bold seeds with brown testa (generally up to five seeds), and the seeds can be compared to apple seeds that contain cyanide and when eaten in large quantities are toxic. The texture of the peel is smooth to slightly soft. The color of pulp is white to light yellow to orange with 6.7–17°Brix, sweet to slightly acidic and juicy as well. The edible portion is known as thalamus similar to other pome fruits. Basically there are two main types of loquat fruit, red and white, where distinct carotenoid accretion leads to changes in fruit color and nutritional differences (Zhou et al. 2007).

30.1.4 Development and Maturation

Bees generally pollinate loquat, but few varieties are self-infertile and some are partly self-fertile. The primal flush and late flush tend to have aberrant stamen and very less viable pollen. An alternate bearing pattern has been observed under moist conditions that can get modified by cluster thinning in heavy commodity years (NIPHM 2015). The most favorable condition for *E. japonica* prolificacy and quality is found closer to sea. Mild climate with uniform rainfall is required throughout the year for its proper growth. The light, well-drained, profound, damp, alluvial soil (gritty subsoil about 1.5 m deep) is perfect for growth. An average temperature of about 20 °C is well suited for its growth in temperate and subtropical areas (Hasegawa et al. 2010). Temperatures lower than −5 °C can harm the flowers and those lesser than −12 °C are fatal (Orwa et al. 2009). Seeds or seedlings grafted on to another tree can be used for propagation (Ojima et al. 1999). The plant once established becomes tolerant to drought and slight frost. Generally, the plant bears fruits in the third year of the habitation and highest yield starts from 15th year. Harvesting is done mainly with matured fruit and TSS above 9%. And full maturity is attained within a period of 90 days. Development of loquat fruit generally occurs in two phases:

(a) Growth phase depicted through the excrescency of the seed
(b) Maturation phase, the later part of which is showed by ripening-related modifications

During maturation the fresh weight tends to increase and sugars start accumulating (Pareek et al. 2014). Determination of ripeness is not simple but is essential to consider, as the unripe fruits are excessively acid (Morton 1987).

30.1.5 Nutritional Profile of Loquat

Flavor and taste play a significant role in maintaining loquat quality characteristics and are related to the degree of sweetness, acids, and volatiles (Guarrasi et al. 2011). Consumer's choice of loquat fruit is based on certain outer fruit characteristics such as shape, color, size, as well as lack of skin defects (Baljinder et al. 2010). Moreover, the fruit weight, diameter, seed count, and flesh firmness are some of the important factors contributing to its quality (Garen et al. 2016). Loquat fruit and leaves have high percentage of phosphorus, potassium, iron, calcium, dietary fibers, as well as pro-vitamin A. Vit. A content provides around 51% of the total value per 100gms. Succinic, fumaric, tartaric, and ascorbic acid are present in lesser concentrations. The predominant acid present is mallic acid that accounts for 90% of all the different acids present (Ding et al. 1998). By nature it is low in sodium and fat and considered as cholesterol-free. The calorie content provides about 47 calories per 100 gms (Table 30.3). The major sugars in ripe loquat flesh are glucose, fructose, and sucrose with sorbitol in lesser concentration. Ninety percent of the sugars in ripe fruit accelerate within 2 weeks of maturity.

Loquat is considered as a delicious summer fruit with 60–70% of the pulp relying on the cultivar with 15–20 gms of seed. The pulp contains 88% water, 9.6% carbohydrates, 1% fibers, 0.6% proteins, 0.5% minerals, and 55 IU of Vit. A (Table 30.3). Being perishable with a shelf life of 3–4 days, various postharvest handling methods are required to increase the shelf life like low temperature conditions, accelerated and controlled atmospheric storage, sulfur and calcium

Table 30.3 Nutritional profile of fresh loquat fruit along with percent of Recommended Daily Allowance (RDA) of the nutrients

	Nutritive value	RDA (%)
Calories	47Kcal	2.4
Total sugars	12.14 g	9
Proteins	0.43 g	2
Total fats	0.20 g	1
Dietary roughage	1.70 g	4
Vit. A	1528 IU	51
Vit. C	1 mg	2
Riboflavin	0.024 mg	2
Pyridoxine	0.100 mg	8
Thiamin	0.019 mg	2
Folate	14 μg	3.5
Potassium	266 mg	6
Calcium	16 mg	1.6
Copper	0.040 mg	4.5
Iron	0.28 mg	3.5
Manganese	13 mg	6.5
Magnesium	13 mg	3
Phosphorus	27 mg	4

treatment, heat treatment, nitrogen treatment, chitosan coating, etc. (Rui et al. 2009, 2010; Zheng et al. 2000).

30.2 Antioxidant Properties of Fruit, Juices, Seeds, Peels, Waste, and Its Products

Fruits and vegetables are considered to be the hub for various antioxidants being present in tremendous amounts in them. This constitutes vit. C, vit. E, carotenoids, flavonoids, phenolic acids, and many other unidentified compounds (Surh 2003). And all these constituents have become an important parameter for considering the fruit quality (Kalt et al. 1999).

Bioactive compounds like phenolics (benzoic acid and hydroxycinnamic derivatives) and terpenoids have been separated and defined for better approach toward the chemical pathway underlying the biological activities of loquat extracts (Liu et al. 2016). Preferable quantities of secondary plant metabolites like flavonols, procyanidins, anthocyanins, and carotenoids are also present. These minute dietary components are proposed to play an important role in humans by relieving the oxygen and nitrogen reactive species to react during the chain reaction of any human pathology (Song et al. 2010). Of the carotenoids the most liberal ones are β-carotene, lutein, violaxanthin, β-cryptoxanthin, γ-carotene, and α- carotene (Kon and Shimba 1988).

30.2.1 Fruit

The antioxidant activity of loquat fruits is due to the proximity of hydroxycinnamic and benzoic acids consequent and cyanidine glycoside. The fruit is many a times used as a narcotic and is thought to prevent nausea and thirst. Mutational alterations in fruit help in the perfectness of color, profoundness of texture, and release of flavor making the fruit highly acceptable to consumers (Kumar and Pallavi 2014). The fruit seed is a unique source of minerals, tannins, starch, and proteins (Table 30.4). The primary organic acid in unripen loquat fruit is malic acid and accounts for 90% of all the other acids, viz., citric, succinic, and fumaric (Ding et al. 2001).

30.2.2 Leaves

Loquat leaves are rich sources of phenolic substances including flavonoid and triterpenoid compounds like ursolic and oleanolic acids with a potential for diet-based hyperglycemia management and are believed to impart many other health benefits such as anti-inflammatory/antitussive (Nishioka et al. 2002), antioxidant, antimicrobial, antiviral, cytotoxic (Ito et al. 2000), hypoglycemic, and hepatoprotective effects (Wang et al. 2015), NF kappa B- inhibitor, nephropathy and chronic bronchitis (Singh et al. 2010). Phenolic compounds like chlorogenic

Table 30.4 Biologically active compounds of *Eriobotrya japonica* fruits

Phyto-elements	Presence
Tannins	–
Alkaloids	+
Saponins	–
Glycosides	+
Terpenes	–
Phenolics	–
Flavonoids	+
Carbohydrates	+
Proteins	–
Steroids	–

Source: Shafi and Tabassum (2013)

acid and flavonoids like quercetin showed significant inhibition of α-amylase and α-glucosidase enzymes (Oboh et al. 2015). Shafi and Tabassum in 2013 also revealed that tannins and flavonoids from the plant extracts are well known to possess antihyperglycemic and hypolipidemic activity.

30.2.3 Peel

The fruit peel mixture had more convincing antioxidant activity as compared to the pulp when observed by DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging assay, β-carotene bleaching assay, and the rancimat method (Delfanian et al. 2015).

30.2.4 Seed

Seeds of loquat have the property to decrease oxidative stress as studied in adriamycin-induced nephropathy rats. As the reduced glutathione levels in renal tissue increased and the lipid peroxide levels in plasma and renal tissue lowered, the oxidative stress is controlled (Hamada et al. 2004; Tanaka et al. 2010). High antioxidant enzyme activity as well as reduced lipid peroxidation in liver tissue of rats with non-alcoholic steatohepatitis has also been observed (Yoshioka et al. 2010). Many toxic alkaloids like cyanogenic glycosides are also found in the seeds which when consume may cause vomiting, breathlessness, and even death also. Therefore, direct chewing of seeds should be avoided as it contains small amounts of cyanogenic glycosides (Mishra and Sharma 2019). Waste loquat kernel can also be used as substrate in submerged culture of *Sclerotium rolfsii* MT6 for scleroglucan production. The protein and the carbohydrate content of the kernel is about 22.5% and 71.2% which is the major reason for using the kernel both in dried and powdered form for scleroglucan production (Taskin et al. 2010).

30.3 Bioactivities of Loquat Extracts

30.3.1 Pharmacological Activities and Bioactive Components

Nine different triterpenes separated from the callus tissues are ursolic acid, 2alpha-hydoxyursolic acid, oleanolic acid, tormentic acid, maslinic acid, 2 alpha,19 alpha-dihydroxy-3-oxo-urs-12-en-28-oic acid, hyptadienic acid, and a mixture of 3-O-trans-p-coumaroyl tormentic acid and 3-O-cis-p-coumaroyl tormentic acid have shown a suppressive effect as that of (−)-epigallocatechin gallate (EGCG) from green tea on the activation of Epstein-Barr virus early antigen (EBV-EA) translated by 12-O-tetradecanoylphorbol-13-acetate (TPA). Among these 2 alpha,19 alpha-dihydroxy-3-oxo-urs-12-en-28-oic acid was considered to be the most potent suppressor resulting in a significant delay of two-stage carcinogenesis on mouse skin (Taniguchi et al. 2002). The triterpene carboxylic acids of oleanolic and ursolic acid from loquat leaves are known to suppress lymphoid leukemia molt 4B cells. The same was confirmed by an in vitro trial test where ursolic acid had shown to inhibit ornithine decarboxylase (ODC) activity by 25.9 and 39.7%, respectively (Komiya et al. 1998). Ursolic acid is considered as one of the active components of the leaf extract and may also have the ability to prevent skeletal muscle atrophy (Cho et al. 2017) and stimulate muscle hypertrophy in vivo study. The antimutagenic activity of the ethanolic extracts of ursolic acid is confirmed by the suppression of *Salmonella typhimurium* TA100 reverants per plate (Young et al. 1994). In addition to epicatechin, 3-caffeonylquinic acid, 5-caffeonylquinic acid, and procyanidin B_2 are also present and are biologically active compounds. The ethanolic extract of *Eriobotrya japonica* fruit has been found to be effective on maintaining blood glucose levels and improvising hyperlipidemia (analysis shows using 70% of either ethanol or methanol of the seed controls liver fibrosis in hepatopathic rats) and other metabolic aberrations and thus can be used as a therapeutic target in diabetics research (Shafi and Tabassum 2013). The leaf extracts also show antithrombotic potential. The active sesquiterpene glycoside like ferulic acid and 3-O-α-L-rhamnopyranosyl-(l, 4)-α-L-rhamnopyranosyl-(1, 2)-[α-L- (4-trans-feruloyl) rhamnopyranosyl- 3-O-α-L-rhamnopyranosyl-(l, 4)-α-L-rhamnopyranosyl- (1, 2)-[α-L- (4-trans-feruloyl)-rhamnopyranosyl-(1, 6)]-β-D-glucopyranosyl nerolidol has the capacity to lower down 50% of the tissue factor at 2 and 369 μmol/L, respectively (Ferreres et al. 2009). Unsaturated fatty acids like linoleic and linolenic and sterol b-sitosterol can also be extracted by the seeds and can be used for functional improvisation of the liver (Nishioka et al. 2002). Maslinic acid has also been found to have a profound anti-inflammatory effect. Phytochemicals like pomolic acid and other related triterpenoids also showed anti-HIV activity. Remains of 3-O-acyl ursolic acid are also found to be beneficial against AIDS virus (Kashiwada et al. 1998). Table 30.5 shows different biological active compounds and their presence in different parts of loquat.

Table 30.5 Biologically active compounds and their presence in different parts of loquat

Biological activity	Plant	Leaf	Fruit
Anticancerous	Caffeic acid, kaempferol	Benzaldehyde, rutin	
Antimutagenic	Caffeic acid, kaempferol, quercetin	Rutin, ursolic acid	Cryptoxanthin
Anti-nitrosaminic	Caffeic acid		
Antioxidative	Caffeic acid, cyanidin, kaempferol, quercetin	Oleanolic acid, rutin, ursolic acid	
Anti-peroxidant	Caffeic acid and quercetin		
Antitumor	Caffeic acid and quercetin	Benzaldehyde, rutin, oleanolic acid, ursolic acid	

Source: El-Hossary et al. (2000) and Singh et al. (2009)

30.4 Health Benefits

As medicinal plant:

- The leaves were being used since ancient times in Chinese traditional medicine and have been suggested to prevent skin disorders, chronic bronchitis, coughs, cancer, ulcers, phlegm, and diabetes (Ito et al. 2000). The leaves vividly reduced swelling in lungs in alveolar macrophages and edema in the ear and paws of rat (de Lopes et al. 2018).
- Leaves have the tendency to prevent ovariectomy-induced bone mineral density retrogradation.
- Loquat leaves are also widely used in the preparation of oriental herbal teas popularly known as "Biwa Cha" in Japan (Tan et al. 2014). For tea preparation the leaves are generally roasted at 350 °C for 30 min and are now used as a health beverage (Zar et al. 2014).
- The extracts of leaf and/or seed are beneficial in preventing and controlling type-1 and type-2 diabetes (Tanaka et al. 2008). Seed extracts also showered in vivo anti-inflammatory result on hamsters by preventing mucositis, bacterial infection, and epithelial lesion brought by chemotherapy and allergic dermatitis (Sun et al. 2010).
- The tanniferous leaves are astringent and anti-diarrhetic. These can also ease diarrhea and depression and counteract intoxication. Leaves can also reduce swelling.
- The leaves' extract also display antispasmodic activity. They are usually used in coryza, hyperemesis, especially nausea in pregnancy, dyspepsia, and epistaxis (Singh et al. 2010; Murakami et al. 1993).

- Loquat extracts made from combining water and ethanol have the potential to inhibit breast cancer and the growth of tumor cells at different stages of progression. This was being studied through Kim et al. in (2011) on doing rat study.
- Loquats are mostly suggested in case of excess kidney stones, uric acid, and kidney failure. It acts as a diuretic by metabolizing the production of urine and elevating the removal of excess uric elements. Regular consumption is beneficial against common cold and in treating various chronic liver diseases like cirrhosis, hepatitis, and liver degeneration (Huang et al. 2006).
- The anti-*Helicobacter pylori* activity of the loquat plant is because of the presence of anti-nutritional factor (proanthocyanidins that are hydrolyzable tannins) in them (Perry 1980).

30.5 Industrial Uses

30.5.1 As Food

E. japonica are generally liked to be eaten raw but can be stewed and cooked as sauce, syrup, jelly, chutney, and jam and are often sufficed poached in light syrup. Immature fruits are used for making pies and tarts. It can be mixed with different fruits in the preparation of salads as well as fruit cups (Ercisli et al. 2012). The seeds are generally used to flavor drinks and cakes. Temiz et al. (2012) have also prepared loquat-enriched yoghurt, the acceptability of which was high among the consumers on the basis of sensory evaluation. The high acceptability of loquat is due to its peculiar flavor and functional compounds. However, due to its low shelf life and short availability, processing into different forms is a must (Hasegawa et al. 2010; Sanches et al. 2011).

30.5.2 Fodder

Tender branches are used as fodder in India and in East Africa. The wood is desirable for making poles, carving, posts, and drawing objects such as stringed musical instruments and rulers. It is also used as firewood (Kumar and Pallavi 2014).

30.5.3 Loquat Wine

Bearing small fruits, the species of *E. cavaleriei* is generally used to prepare alcoholic drink. The fermented product is believed to contain increased amounts of calcium, iron, phosphorus, and magnesium. Though the seeds and kernel contain cyanogenic glycosides, the drink is prepared from the varieties like Mogi and Tanaka that have no risk of cyanide poisoning (Joshi et al. 2017). In fact loquat fermented milk was also prepared by using the probiotic strains of Str. *thermophilus,* *L. acidophilus, and B. bifidum* of which the count for *Str. thermophilus,* stage was the highest followed by *L. acidophilus* and *B. bifidum (*Allah 2019).

30.5.4 Miscellaneous Uses

Big leaves of *E. japonica* trees are desirable for mulch and thus can be used for improving soil quality. *E. japonica* is often grown as an indoor pot plant for ornamental purposes. In the Kilimanjaro region of East Africa, the tree is commonly grown on the borders of home compounds as a barrier or support. The seeds are toxic and should be separated while cooking the fruits, and the fruits can be used as an insect repellent (Sun et al. 2010).

30.6 Conclusion

Loquat is well known for its curing ailments since historic times. The fruit either consumed raw or in fresh form has numerous health benefits. With the presence of pharmacologically functioning compounds in plant extracts and their structure-activity relationships, the efficiency and the extraction of various phytochemicals as well as natural compounds have received much attention as they are safe for human use (Liu et al. 2016). The leaves are widely used in the form of traditional medicine for treating common cold, cough, cancers, etc. Therefore it can be evaluated that the fruit is having high potential to be used as a functional, nutraceutical, and therapeutic food product. Though the fruit is significantly important, little attention has been given mainly because of its perishability and short shelf life. Various preprocessing treatments are available and are being implemented for preventing its spoilage thereby prolonging its shelf life. If the rate of perishability can be controlled, during its production season then the fruit can act as boon for both medicinal and pharmaceutical purposes.

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Blueberries

31

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Abstract

Blueberries are perennial fruits belong to *Ericaceae* (family), *Vaccinium* (genus), and *Cyanococcus* (section) prostrate shrubs. They are called superfoods according to various food scientists as well as industries due to its flavor, taste, and potent antioxidant activities in the human body. In the last two decades, there has been a consistent demand for blueberries because of its dietary values that offer multiple health benefits across the world. North America, Canada, and other European countries are meeting the needs of the global markets, whereas India has also started its cultivation in collaboration with the pioneer producers. Blueberries are classified into two major types, high bush and low bush, in addition to rabbiteye and half high (crossbreed). As per consumers demand, blueberries are available as ripe fruit, dried, frozen, jam, jelly, juices, powder forms, and other cooking purposes. Blueberries contain flavonoids under polyphenols group (anthocyanin, flavonols, flavanols), tannins as nonflavonoids, and hydroxycinnamic acids. Further, good amounts of ascorbic acid, vitamin K, vitamin B9, magnesium, and dietary fiber are also present. Anthocyanin along with other polyphenols in blueberries altogether perform antioxidant roles in diabetes, antiaging, hypertension, hyperlipidemia, bones, eye health, and cancer.

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Keywords

Blueberries · Antioxidant · Blueberries benefits · Superfoods · Immunity-boosting fruit

31.1 Introduction

Blueberry is a perennial functional fruit, available in blue or purple color. They belong to *Ericaceae* (family), *Vaccinium* (genus), and *Cyanococcus* section plants. Blueberries are consumed by raw, dried, cooked, jelly, and other forms also. Blueberries are well accepted in the global market because of many antioxidants, anti-inflammatory actions. Blueberries contain anthocyanidins, ascorbic acid, chlorogenic, pyruvic acid, and other bioactive compounds which altogether perform free radical scavenging. Therefore, blueberries can protect a human body from a lot of lifestyles disorders and other chronic diseases, including diabetes and cancer (Ma et al. 2018). They are commercially available and consumed in the name of the low bush (wild) and highbush (cultivated) by berries lovers all across the world. As per market-wise demand and trend, blueberry has become more popular in the USA, Canada, and European countries; even Asian countries are also on growth to meet the requirements of these superfoods. The typical bilberry, called European blueberry (*Vaccinium myrtillus*) is also famous in European countries having similar antioxidant properties. They are equally beneficial in menstrual disorders, eye health, and other health issues (Strik 2006; U.S. Highbush Blueberry Council 2020).

Here are the scientific details: (Cabi 2020).

Common Name: Blueberry
Botanical Name: *Cyanococcus*
Scientific Name: *Vaccinium corymbosum*
Taxonomy:
Domain: *Eukaryota*
Kingdom: *Plantae*
Phylum: *Spermatophyta*
Subphylum: *Angiospermae*
Class: *Dicotyledonae*
Order: *Ericales*
Family: *Ericaceae*
Genus: *Vaccinium*
Species: *Vaccinium corymbosum*

Blueberries are small, approximately 0.2–0.6 inches (5–16 mm) size, low-calorie, trendy fruit having very high nutritional benefits. The fruit is a strong antioxidant by its dietary fiber, vitamin C, vitamin K, and magnesium apart from polyphenols. A large numbers of food scientists, nutritionists, researchers, industry, and common people across the globe have already accepted that blueberries are superfood due to their antioxidant activities (Gerald et al. 2015; Mirsky 2013).

History The most popular blueberries are mainly cultivated and produced from North America, followed by Canada, and European countries (Strik 2006).

Here is a growth history of blueberries:

Year	Blueberries history of cultivation
1893	A cranberry grower's daughter, Elizabeth White, found the potentialities of farming blueberries (Whitesbog Historical Village 2014).
1908	Frederick Coville (a US botanist) started to cultivate once he found its benefits.
1910–1912	Frederick discovered blueberries officially, and wrote *Experiments in Blueberry Culture*. He collaborated with Elizabeth and started cropping successfully in White's farm (HGO Farms 2016).
1916	Elizabeth and Frederick jointly began harvesting and sold first highbush blueberries (Mirsky 2013).
1917	Blueberries packaging was started this year in the USA.
1932–1962	Above 2 lakhs seedlings were spread throughout the USA, and Elizabeth White got an award for her exceptional contribution in blueberries agriculture in 1932.
1971–1981	Various farming experiments about violet blueberries: understanding of its importance. July month was declared "National Blueberries Month" in 1974 by USDA. Further, Ronald Reagan created a blueberry jelly belly, and during this tenure, total sales become 6000 lb. (U.S. Highbush Blueberry Council 2020; U.S. Department of Agriculture 2011).
1990–2000	Scientists focused on its antioxidant benefits and started applying in health, nutrition research, and in Ayurveda. India also started harvesting, planting like American states and other countries. (U.S. Highbush Blueberry Council 2020; Mirsky 2013).
2003	New Jersey declared "State Berry" (Mirsky 2013).
2010	Blueberries became "little blue dynamos."
2011	Plantation in the White House kitchen garden in the USA.
2012	The various forms of blueberries were available in more than 4000 products, including cosmetics and pet feed in American states (U.S. Highbush Blueberry Council 2020).
2013–2014	Blueberries were served in every restaurant among all the states of America and European countries; as a result, cultivation crossed more than 1 billion lb. (Burton 2017).
2015–2016	USA celebrated blueberries as a centenary year.
In India:	Blueberries are abundantly available in rural India during the summer. Local vendors are selling this fruit through mobile hawkers because it is one of the cheapest and readily available fruits (Hey 2019; Parmar 2019).

31.1.1 Production

Global Level In developed countries, there is a trend to consume both the blueberries, highbush (cultivated) and low bush (wild). In addition to that, concentrated, frozen, canned, and dry types are also on demand due to various readymade tasty food products for domestic purpose, for example, spreads, fruit juice, or flavoring (Mirsky 2013*)*. The USA and Canada produce almost 95% of entire blueberries in the world market. North America is the pioneer of high bush blueberry plants production as a native place, although other countries are also procuring different varieties (U.S. Department of Agriculture 2011). There is a significant growth of farm-fresh blueberries to export from the USA, Canada, and other European countries to rest of the world markets. After the USA, the second-largest producer is Canada in terms of farming both the varieties of blueberries (*HGO Farms* (2016)).

Figure 31.1, presented below, shows the highest percentage of blueberries fruit cultivation in Canada. Out of all fruits, blueberries ranked top (16.7%) followed by apple, grapes, strawberries, peaches, raspberries, cranberries, and six more popular fruits (Wild Blueberry Fact Sheet 2020).

Poland was ranked in the third position because of 13,000 tons per year production followed by Germany 10,000 tons in a year (Table 31.1). In the functional foods market, European zone has been growing consistently as per market demand. Bilberries or European blueberry cultivation has taken a major role in the European countries apart from import of high bush blueberry from the USA.

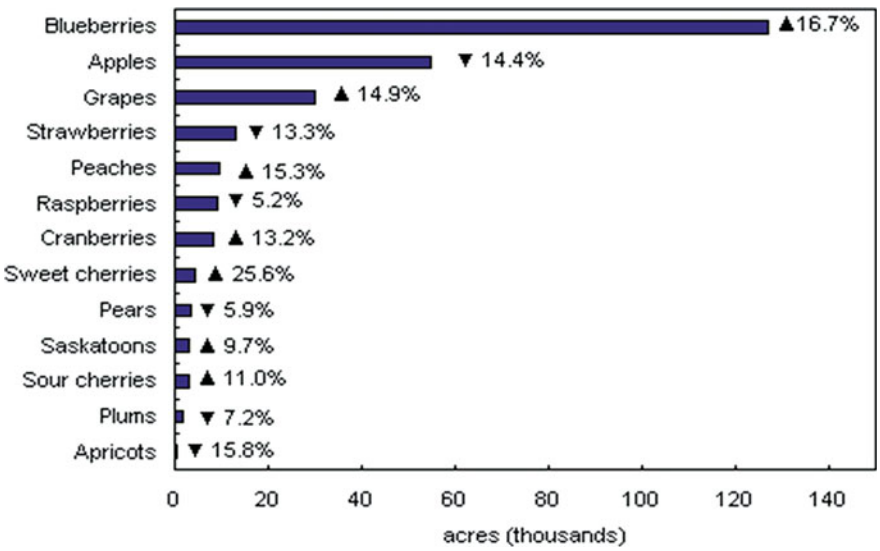

Fig. 31.1 Comparisons of all fruits cultivation in Canada and blueberries ranked top (year: 2001–2006). (Source: Statistics Canada, Census of Agriculture, 2001 and 2006)

Table 31.1 Top 10 blueberry producing countries in 2016–2017 -financial year. (Burton 2017)

Position	Countries	Production (tons)
1st	USA	240,000
2nd	Canada	109,000
3rd	Poland	12,730
4th	Germany	10,280
5th	Mexico	10,160
6th	France	9000
7th	Netherland	5500
8th	Spain	5000
9th	Sweden	2890
10th	New Zealand	2720

Altogether the revenue was increased from US$1.8 billion to US$8 billion approximately during the tenure of 1999–2006 (Burton 2017; Basu et al. 2007).

Production in India There is insufficient data about blueberry cultivation and production before 2000 in Indian history. Blueberries are available in India but not all varieties like in the US and Europe. Since decades, there are so many business initiatives taken in India with the collaboration of the USA, Canada, and other European countries. The fruit was unknown in India 20 years back, but currently, they are under regular productions in Himachal Pradesh, near Kullu, with a tie-up of CSK Himachal Pradesh Agriculture University, Palampur, and other foreign companies (Hey 2019; Parmar 2019). India's I.G. International has a joint venture (a company named as Berry Life) with Australia's Mountain Blue; together they have taken a high initiative to produce and market mainly in southern and western India. The US-based Munger Farms, the world largest berry producer, having 3000 acres and INI Farms in India together started business of many blueberries, keeping in mind the unlimited demand in the domestic market. The primary focus and initiatives were taken on importing blueberries from Munger Farms (US-based company's operations in India) and partner farm, the "Naturipe." The Munger Farms also supplies other berries and dry fruits due to consistent demand in Indian markets (Hey 2019).

Cultivation in Indian Climate Blueberry bushes are well suited with winter chill varying from 400 to 1100 h as per seedling types. The essential part is soil which should be acidic with a pH value of 4.2 to 55.0 in addition to the presence of adequate moisture but not dry weather.

Harvesting and Yield (Indian Perspective) Usually, blueberries farming takes about 6 weeks from flowering to full-grown fruit through the clustering process (5–10 clusters). A typical plant can produce up to 5 kg of fruits but picking up the fruits from the plants is more expensive than other steps. The country like India, where blueberries business is expected to be much better due to the availability of cheaper labor than developed countries. Further, cold weather, hilly areas with acidic soil in northern India, and high demand among Indian people would be favorable conditions to grow a good amount of blueberries. As per current scenarios, Indian people are buying online not only fresh blueberries but also dried berries, jams, and juices, considering their health benefits (Parmar 2019).

31.1.2 Botanical Description

There are typically four types of blueberries.

High bush (*Vaccinium corymbosum*): This type of each blueberry is usually 1–8 cm long and 05–3.5 cm broad. The blueberries typically grow at very steep hills, having chilled weather and suitable soil. They are called perennial, and deciduous shrubs which always prefer to grow at sandy areas (Becky Sideman 2016).

(i) Low bush (*Vaccinium angustifolium*): This is also named as wild type blueberry, which is small in size and very sweet, available abundantly in New England. The plants are shrubs, short in height, and grow only in little acidic soil as well as cold weather. Low bush varieties reproduce through cross-pollination by which mother plant grows rhizomes (stem) and create a clone. Subsequently, floral bud and leaf buds flourish into few flowers and ultimate fruits (Wild Blueberry Fact Sheet 2020).

(ii) Rabbiteye (*Vaccinium ashei*): Rabbiteye variety needs medium chilled weather, available sufficiently in Argentina and some other countries. This type of blueberry has the trait of self-incompatibility. So, by applying cross-pollination, a massive self-grown culture of this blueberry can be done in the chilled region, especially in the areas like Himachal Pradesh in India (Rowland et al. 2010).

(iii) Half-high type: This has been typically produced by fruit breeders due to instant commercial demand globally, more in quantity rather than quality. The berries are produced by crossing (hybridization) into the two breeds – high bush and low bush (Strik et al. 2014).

The ultimate fruit**:** At last fruits come, and they measure around 5–15 mm in length and look like light greenish initially, followed by reddish-purple, and the last stage ripe one shows deep purple color. Fruits are by default covered by the protective coating of wax, which altogether are called “bloom” (Blueberry Information 2013).

31.2 Antioxidant Properties

All berries belong to *Ericaceae* family such as blueberry and cranberry contain bioactive compounds (BAC) which are mainly phenolic compounds or polyphenols that are usually responsible for better nutritional benefits. The best bioactive compounds are phenolic acids, anthocyanins, flavonols, tannins, and ascorbic acid (vitamin C), etc. Blueberries are superfoods because they are one of the best natural antioxidants, containing all the important polyphenols along with few simple phenols. Hence, there is the reason for the high demand for blueberries that is growing day by day for dietary applications worldwide (Parmar 2019; Becky Sideman 2016; Skrovankova et al. 2015).

31.2.1 Fruit

In the daily balanced diet, fruits contribute a lot in terms of water content, multivitamins, minerals, and total antioxidant properties. In the list of the fruits, all berries are very popular because of nutritional benefits.

Blueberries grow with various phases of maturity. Here are the stages mentioned serially: (i) immature green, (ii) greenish pink, (iii) bluish pink, and (iv) ripe (deep blue/hazy blue). Researchers already revealed that the antioxidant potentialities of the blueberries are superior to other berries and their juices in some perspectives. In general, the anthocyanin content is average in naturally farming blueberries cultivated in the countries which are rich in blueberries production. In the province of Rio Grande do Sul, Brazil, the organic Rabbiteye blueberries reached high quality commercially so far due to the high amount of anthocyanin ((Reque et al. 2014a, 2014b, 2014c). In general, the fruit is also named a “longevity fruit” because of its high immunity-boosting capacity by scavenging free radicals. It may decrease the chances the risk of so many noncommunicable diseases (NCDs) often face by a large number of people in the world (Halliwell 2006).

31.2.2 Juices

Blueberry (*Vaccinium myrtillus*) juices are commonly on-demand in both the markets, online and offline, due to their antioxidant properties. The juices are the excellent sources of anthocyanins (approximately 4 mm anthocyanins/g extract). They are hyperglycemic, neuroprotective, antiaging liquid supplements in the foods products market. A study found that the total polyphenol and anthocyanin existences are better in blueberries juice than other berry juices. Cranberries and blueberries, both juices are only capable of preventing tyrosinase, dipeptidyl peptidase-4, monoamine oxidase A (MOA), and α-glucosidase if administered in the right doses. However, in some aspects, food scientists are recommending cranberry juice is better than the best (Cásedas et al. 2017).

31.2.3 Seeds

Blueberry is such a wonder fruit, which can be used for its every part. Blueberry seed oils are marked for their total phenolic content (TPC), unsaturated fatty acid composition, tocopherol, and carotenoid in addition to peroxide value and oxidative stability index. Blueberry and its various products contain polyunsaturated fatty acids. Similarly, the seed oils are having of alpha-linolenic acid (19–32 g/100 gm of total fat), along with a low ratio of omega-6/omega-3 fatty acids (1.64–3.99) (Parry et al. 2005). Seeds oils are produced from berry juice as a by-product in a proper food processing method. While processing the berry seed oils, all respective components are stored and appropriately isolated by following up the protocol of uses of temperatures and chemicals (Van Hoed et al. 2009).

31.2.4 Peels

Blueberries are eaten whole, hence peeling or removing the skin is not required. However, for a hygienic reason, proper washing is recommended before eating all the berries. As far as anatomy is a concern, the skin is very soft and full of fiber. Regarding juices production from berries, the liquid is kept separate as a paste which contains the peel and seeds both. Skin also contains anthocyanins, which play a significant role in health beneficial effects in neurodegeneration, cardiovascular diseases, all types of diabetes, and cancer, etc. If eaten raw but fresh, then skin and seed have a much lower moisture content than the whole berries, and also they ensure better moistures and shelf life (Van Hoed et al. 2009).

31.2.5 Wastes

In the processed products from blueberries, for example, jam, juices, etc., the frequent occurrence is the reduction of nutritional benefits due to the low amount of anthocyanins usually present in the raw fresh fruits. Although insufficient data is available, but few studies show that there are no such changes of macro or micronutrients reported in processed foods. That is due to proper and uniform biosynthesis of anthocyanins in high bush and rabbiteye blueberries. Following a change of color from green to blue usually at July end, the fruit becomes fully ripe that shows deep blue or black-blue coloring. As per common fruit lifecycles, blueberries also emerge small, green in color, and raw as nonedible fruit and gradually turn into the ripe fresh fruit with the increasing amount of anthocyanins. The complete maturity means the deep blue color fruit available with some green leaves. The leaves also contain anthocyanins that perform defensive mechanism toward photoinhibition, photorespiration, and xanthophylls (Hoch et al. 2001; Trehane 2004).

31.2.6 Antioxidant Properties of Products Prepared from Blueberries

Blueberries can be served with other foods and daily meals. Fresh blueberries are also used in baking and flour. Dried blueberries and high bush blueberry juice are much in demand due to their nutrients benefits and bioactive products (BAC). Antioxidant properties are assured at a maximum level only when farming is done following the proper scientific methods. Antioxidant action is a quality output of scientific cultivation starting from seedlings stage till delivery at customer's place, that is, farm to fork. The secret is that the particular polyphenols and other BAC present inside in blueberries deliver the health benefits only if systematic cultivation and preservation are followed (Gough 1994). General preservation, another process of blueberries, is to use chilled weather during the cold winters in North America and other surrounding countries. Sun-dried or average dried temperature can also be considered for drying with smoke. In some cases, solar energy is utilized as an alternative where no drying temperature is available. The dried blueberries are eaten in bread and pancakes or other big size cakes which are available in dessert shops or virtual stores having an increasing demand. Powdered dried blueberries are getting popular, mixed with parched grain or staple meal. They are also added in various fishes and meat gravy to make them tasty and nutritious (Gough 1994; Trehane 2004).˙There are plenty of blueberries recipes as per the foods habits of the respective countries; a very few have been discussed here.

31.3 Processing and Preservation

Blueberries are available for purchase in the form of ripe fruits, frozen, and processed such as canned, dried, juiced, jelly, jams, beverages, and types of yoghurts for various public demand across the globe. Approximately 50% of mature fresh blueberries are available as processed foods, which are consumed in the forms of different products as per market demand. In the processing and preservation methods, drying by hot air, freezing and thawing, osmotic applications, and microwave-drying techniques are applied. In recent days, packaging in modified environments, freezer storage, irradiation of ultraviolet, and sulfadoxine (SO_2) fumigation methods are used as post-harvesting and preservation techniques. The best scientific methods and procedures have been implementing in the blueberry cultivation to control nutritional deterioration by increasing shelf life (Strik et al. 2014; Skrovankova et al. 2015).

31.4 Chemical Compounds and Their Biological Pathways Involved in Antioxidant Proprieties

In general, all berries contain the bioactive compounds (BAC) which influence the antioxidant activities through some biochemical reactions. In blueberries, antioxidants are present as fruit colorants such as carotenoids, anthocyanins, and other phenolic compounds. There are a different group of compounds present in the polyphenols available in blueberries. The compounds are hydroxycinnamic acid and hydroxybenzoic in the group of phenolic acids and anthocyanins, flavonols, and flavanols under flavonoids group. Similarly, other bioactive compounds such as tannin are divided into hydrolyzable and condensed tannins (proanthocyanidins). Even one of the most used BAC available in citrus fruits is ascorbic acid, that is vitamin C (De Souza et al. 2014; Slatnar et al. 2012; Basu et al. 2007). The added advantage is blueberry phenolic compounds are transformed by the metabolism and microflora present in the colon into a similar kind of molecule that can remain unchanged and subsequently work in the inflammatory places in vivo (Limberaki et al. 2012; Verotta et al. 2015).

During stress and other conditions such as inflammation and infection, oxygen molecules break into single atoms which contain unpaired electrons. In this circumstance, many free electrons are available due to infections or inflammations that affects the skin, hormones, external organs, and other human body parts. The body needs a protective agent like an antioxidant supplement in a balanced diet to reduce the free radicals, including oxidative damage to DNA. So, antioxidants are the soldiers in the body which protect our immunity and diseases, including one of the major challenges, cancer. However, the actions of dietary supplements (commercial antioxidants) *need to be* studied thoroughly to get proper knowledge of physiological and biochemical reactions and effects in vivo (Lobo et al. 2010; Limberaki et al. 2012; Verotta et al. 2015).

31.4.1 Biochemical Properties of Blueberries and Mode of Actions of Bioactive Compounds (BAC)

All berries are usually rich in fructose, glucose, water, and other compounds. In addition to that, the right amount of dietary fibers, for example, pectin, cellulose, hemicellulose, etc. are also present. An edible portion of 100 g of blueberries provides some amount of fumaric, malic acid, tartaric, oxalic acid, and a very high amount of magnesium (Nile and Park 2014). Ascorbate, folate, and phenolic compounds together work as phytochemicals. Hence, in the functional foods market, blueberries and its items are called superfoods (Gerald et al. 2015; Skrovankova et al. 2015). Chemical composition of blueberries is variable subject to cultivar, farming places and climate status, feeding and nutrition of plants, ripeness stage, harvesting duration, and lastly storage (Halliwell 2006; Gough 1994).

Bioactive compounds (BAC) or phenolics are under a broad and nonhomogeneous group of chemical compounds containing rings (aromatic) linked with a conjugated form of rings (aromatic) having –OH groups. The components always have an intention to supply a hydrogen atom (electron) to make unstructured molecule into structured, so that antioxidant mechanism goes on consistently in general. This way, various studies show that the phenolic compounds have influential free radicals scavenging activities both in vivo and in vitro (Skrovankova et al. 2015; Nile and Park 2014]. Thus, phenolic compounds perform antioxidant activities both in open and combined forms with sugars and other acids along with compounds such as polyphenols, non-polyphenols, quinines, and condensed tannins as well (Nile and Park 2014). In the cultivation process, proper care is usually taken to retain the overall quality of the BAC and their biochemical properties by the western countries. There are compounds like ascorbic acid (ascorbate), other acids, and polyphenols that remain well maintained from seedlings phase till storage and from storage till delivery in the customer's basket. However, the loss of nutrients depends on the cultivar, favorable environments, laborers, proper transportations, long-term storage, and similar other facilities (Proteggente et al. 2002). Blueberries contain water-soluble vitamins (vitamins B and C) which are good enough for instant consumption but not useful if exposed to unbearable heat or excess sunlight (oxidation), long-term preservation, and other improper domestic uses. These available vitamins perform their free radical scavenging actions by redox reactions. In this context, some studies show that even a small amount in the fruits can matter for actual antioxidant activities in the human body (Atala et al. 2009; Battino et al. 2009; Giampieri et al. 2012).

The most useful bioactive compound in blueberries is anthocyanin, whose stability is practically dependent on the storage of ripe fruits. A study analyzes that up to 59% degradation of anthocyanins can be noticed at the end of 5–6 months of storage. Delphinidin (a glucoside) is another anthocyanin derivative that can show the deterioration of 79.90%, but pelargonidin (a glucoside derivative) has maximum stability (9% loss only) (Reque et al. 2014c). Some experimental studies found that blanching the blueberries at 85 °C or more for 4 min may show about 8%–9% rise of flavonoids compounds (mainly anthocyanin). Further, these compounds' percentage may vary based on thermal-processed system, osmo-dehydration by air 71 °C $\geq$ status, which together may decrease anthocyanin up to 30% (Giovanelli et al. 2012; Giovanelli et al. 2013).

31.4.2 Bioactive Compounds (BAC) in Blueberries

Anthocyanin present in ripe blueberries, as well as other berries under the flavonoids group, constitutes almost 61% of the total polyphenolics. This bioactive compound provides the most significant contribution to blueberry for many health benefits (Van De Velde et al. 2013). The ripe fruits are rich in both flavonoid and non-flavonoid compounds (BAC), and the non-flavonoid polyphenols are useful also due to the esterification roles of chlorogenic and hydroxycinnamic. Flavanols, along with proanthocyanidins, provide synergistic effects in nutrition and immunity systems in vivo (Buran et al. 2014; Fredes et al. 2014; Castrejón et al. 2008; Basu et al. 2010). Anthocyanins are cyanidin (arabinoside, glucoside, galactoside), delphinidin (arabinoside, galactoside, glucoside), malvidin (arabinoside, galactoside, glucoside), petunidin (arabinoside, galactoside, acetylglucoside), and peonidin (arabinoside, galactoside). All compounds are under anthocyanin glycosides derivatives. Similarly, myricetin derivatives (glycosides, glucoside, rhamnoside) and quercetin derivatives (galactoside, glucoside, rutinoside) belong to the flavonoid groups

Table 31.2 Major bioactive compounds present in the blueberries

Anthocyanins:	
1. Cyanidin glycosides derivatives: arabinoside, glucoside, galactoside	Paes et al. (2014), Buran et al. (2014)
2. Delphinidin glycosides derivatives: arabinoside, galactoside, glucoside	Koca and Karadeniz (2009)
3. Malvidin glycosides derivatives: arabinoside, galactoside, glucoside	Taruscio et al. (2004), Correa-Betanzo et al. (2015)
4. Petunidin glycosides derivatives: arabinoside, galactoside, acetylglucoside	Barnes et al. (2009), Taruscio et al. (2004)
5. Peonidin glycosides derivatives: arabinoside, galactoside	Borges et al. (2010), Fredes et al. (2014)
Flavonoids:	
1. Myricetin derivatives: glycosides, glucoside, rhamnoside	Barnes et al. (2009), Borges et al. (2010)
2. Quercetin derivatives: glycosides, galactoside, glucoside, rutinoside	Buran et al. (2014), Fredes et al. (2014)

Table 31.3 Major factors that influence the quality retention at post-harvesting phase

Factors influencing to phenolic compounds	1.Cultivation location	Koca and Karadeniz (2009)
	2.Variety and genotype	Fredes et al. (2014), Castrejón et al. (2008)
	3.Condition of cultivation	Kevers et al. (2014), Castrejón et al. (2008)
	4.Cultivation types and techniques	You et al. (2011)
	5. Processing of juices, pureeing, freezing, blanching, etc.	Reque et al. (2014c), Brownmiller et al. (2009)
	6. Storage (period, temperature condition)	Reque et al. (2014c), Brownmiller et al. 2009

(Giovanelli et al. 2013). Total anthocyanin content (TAC), total phenolic content (TPC), and anthocyanin variances among all commercially available blueberries have been placed in the Table 31.2.

In the Table 31.3, those major factors have been pointed out which are responsible for maintaining and retaining the quality of blueberries during cultivation and harvesting phase as well.

31.5 Nutritional Facts of Blueberries

The nutrients composition of blueberries (highbush and low bush based on American origin) have been provided in the Table 31.4

Table 31.4 Nutritional values in blueberry per 100 g fresh fruit (U.S. Department of Agriculture 2011)

Nutrients	Amount (in gram)	Nutrients	Amount (in gram)
Energy	57 kcal	Energy	240 kJ
Water	84.21	Saturated fatty acid	0.028
Carbohydrate	14.49	Total MUFA	0.047
Protein	0.74	Total PUFA	0.146
Total lipid	0.33	Ash	0.24
Carbohydrate	***In gram***	***Vitamins***	***In Milligram***
NLEA – sugar	9.96	Vitamin B1	0.037
Dietary fiber	2.4	Vitamin B2	0.041
Starch	0.03	Vitamin B3	0.418
Sucrose	0.11	Vitamin B5	0.124
Glucose – dextrose	5.0	Vitamin B6	0.052
Lactose	0	Vitamin B9	0.006
Fructose	5	Vitamin A	54 I.U.
Galactose	0	Ascorbic Acid	9.7
Maltose	0	Alpha-tocopherol	0.57
Amino Acids	***Quantity (in gram)***	Vitamin K	0.0193
Tryptophan	0.003	Betaine	0.2
Isoleucine	0.023	Total choline	6
Threonine	0.02	Iron (Fe)	0.28
Lysine	0.013	Calcium (Ca)	6
Leucine	0.044	Phosphorus (P)	12
Cysteine	0.008	Magnesium (Mg)	6
Tyrosine	0.009	Sodium (Na)	1
Phenylalanine	0.026	Potassium (K)	77
Arginine	0.037	Zinc (Zn)	0.16
Valine	0.031	Manganese (Mn)	0.34
Glutamic Acid	0.091	Selenium (Se)	0.1
Histidine	0.011	Copper (Cu)	0.06
Alanine	0.031	Zeaxanthin + Lutein	0.08
Aspartic acid	0.058	Beta-carotene	0.032
Proline	0.029	Folate, food	0.006
Serine	0.022		
Glycine	0.031		
Methionine	0.012		

31.5.1 Nutrition Value

Apart from the highbush, low bush, and rabbiteye, one of the upcoming popular blueberries varieties is bilberry or European blueberry. This type of blueberry has almost similar health benefits due to the presence of nearly identical nutrients as in cultivated and wild blueberries (Table 31.5). According to the US National Center for Complementary and Integrative Health (US NCCAM), these blueberries are

Table 31.5 Nutritional value in European blueberry per 100gm (Proestos 2018)

Nutrients	Quantity	Nutrients	Quantity
Carbohydrate	***Gram/milligram***	***Vitamins***	***Milligram***
Sugar	14.7 g	Vitamin B1	0
Fiber	3.60 g	Vitamin B2	0
Starch	0	Vitamin B3	0.4
Sucrose	163 mg	Vitamin B5	0.1
Glucose	7222 mg	Vitamin B9	6.0
Lactose	0	Vitamin A	54 I.U.
Fructose	7355 mg	Ascorbic acid	9.7
Galactose	0	Alpha-Tocopherol	0.6
Maltose	0	Vitamin K	19.3
Amino acids	**Quantity (mg.)**	Betaine	0.2
Tryptophan	3.0	Choline	6.0
Isoleucine	23.0	Iron (Fe)	0.3
Threonine	20.0	Calcium (Ca)	6.0
Lysine	13.0	Phosphorus (P)	12.0
Leucine	44.0	Magnesium (Mg)	6.0
Cysteine	8.0	Sodium (Na)	1.0
Tyrosine	9.0	Potassium (K)	77.0
Phenylalanine	26.0	Zinc (Zn)	0.2
Arginine	37.0	Manganese (Mn)	0.3
Valine	31.0	Selenium (Se)	0.1
Glutamic Acid	91.0	Copper (Cu)	0.1
Histidine	11.0	PUFA	100
Alanine	31.0	Omega −6 fatty acid	88.0
Aspartic acid	57.0	Omega −3 fatty acid	58.0
Proline	28.0	Fat (total)	300
Serine	22.0		
Glycine	31.0		

consumed to get benefits against dysentery, diarrhea, menstrual irregularities, and cataract problems. However, there is no such influential literature to prove its efficacy on chronic diseases. The University of Maryland showed that bilberry could be used in both type I and II diabetes as well as cardiovascular diseases, although more studies are required in the health fields. Anthocyanosides in European blueberry (*Vaccinium myrtillus*) can raise rhodopsin which is a pigment responsible for night blindness. Further, tannins are also helpful compounds can be used as an anti-inflammatory agent (U.S. Department of Agriculture 2011).

31.6 Health Benefits

As per some observational and experimental studies, blueberries and its various forms of foods items provide plenty of health benefits. These are not only a potent antioxidant but also a natural antidiabetic, anti-ageing, cardio-protective agent. These are very helpful for the good health of eyes, bones and cartilages apart from weight, blood pressures and cholesterol management. The phytochemicals, e.g. anthocyanins, chlorogenic acid, procyanidins, and other flavonoids are the critical players for health and nutrition benefits in a human body. The major contributor of antioxidant activity is mainly Anthocyanin that takes part 84% of phenolic compounds followed by hydroxycinnamic acids and flavonols (Giovanelli et al. 2013). As per some recent studies, rabbiteye blueberries are believed to deliver better defense mechanism for health scientifically than other cultivars. The reason is perhaps the higher concentration of anthocyanins in the thicker skin than thin skin of the fruit part (Castrejón et al. 2008; Pertuzatti et al. 2014).

Antidiabetic Blueberries have antidiabetic properties and play a protective role in pancreatic β-cells during glucose-induced oxidative stress. They are already famous for sensory evaluation in dietary aspects due to the presence of useful flavonoids, tannins, and ascorbic acid that altogether help cardiovascular system (Al-Awwadi et al. 2005; Martineau et al. 2006).

Bones Health Blueberries contain anthocyanins, proanthocyanidins, and flavonols, which are beneficial phytochemicals for bone protection (Shen et al. 2012).

Ophthalmologic Disorders Blueberries can help patients suffering from cataract and macular degeneration by improving blood and oxygen delivery to the eye. Hence, they work as a potent but cheap and best antioxidant (Calò and Marabini 2014).

Cardiovascular Health Blueberries can be consumed for high blood pressure, hyperlipidemia, hypertriglyceridemia, and atherosclerosis prevention (Wu et al. 2010). Some studies revealed that the blueberries seed oil is safe for hyperlipidemia patients because of only 1.6% presence of saturated fatty acid out of 100 g total content (Basu et al. 2010). Regular and higher than average eating habits of blueberries or strawberries are helpful for myocardial infarction (MI) because of the rich amount of anthocyanins. In a study, the of male patients (37%) reported lesser chance of MI in the case of blueberries' consumption at a regular basis (Adams et al. 2010; Cassidy et al. 2011).

Cancer Prevention Some studies suggest that various glucoside derivatives of anthocyanins may inhibit the proliferation of cells in tumors, colon cancer cells, and breast cell lines in humans. Daily consumption of 300 g of blueberries can reduce oxidative stress and increase antioxidant action by preventing DNA damage and vascular function in males. The fruit significantly reduces hydrogen peroxide–

induced DNA damage, and as a consequence inhibit growth and metastatic progression of cancer cells. Studies assessed that polyphenols and ascorbic acid are strongly correlated with the inhibition of cancer cell proliferation and induce programmed cell death (Samad et al. 2014; Adams et al. 2010; Chen et al. 2005).

Antiaging According to some observational studies, anthocyanins can be beneficial compounds over phytochemicals and some particular flavonoids in case of antiaging foods. More than 50 g daily consumption of blueberry may reduce the risks of some lifestyles disorders, including aging as a typical outbreak for the males as well as females under the age group 40–50 years (Cassidy et al. 2011, 2013; Jennings et al. 2012).

Obesity and Weight Maintenance A study on 2734 healthy female blueberries consumers went on a daily intake of the fruit, measured the fat mass based on dual-energy X-ray absorptiometry (DEXA) method (body composition assessments), and found less central adiposity by 3–9%. The result was observed due to the presence of anthocyanin in the blueberries (Jennings et al. 2017; Bertoia et al. 2016). Another study found 150 g blueberries intake daily can improve vascular function and lipid status. In this case, insulin function remained at the desired level (Rodriguez-Mateos et al. 2012; Jennings et al. 2017).

Blood Pressure Control A group of subjects revealed that 150 g blueberries daily intake sustainably for 42 days may prevent high blood pressure, myocardial infarction, metabolic syndrome, and vascular endothelial function. The status was much better among the middle-age group males by consuming the fruit (Stull et al. 2015).

Type II DM and Other Metabolic Syndromes Three prospective studies on blueberries showed significant control of glucose among diabetes type II patients, including the future risk reduction of 26%. Regular consumptions of flavonoids and anthocyanins through rabbiteye blueberries (*Vaccinium ashei*) in the same cohorts found in the study. Therefore, near about 23% risk reduction is possible if there is an intake of $\geq$2 servings (200 g or more) weekly as per the study conducted (Wedick et al. 2012; Bertoia et al. 2015). In another study, a 12-week trial conducted on 54 overweight young adults who consumed 50 g blueberries as a replacement of 50 g carbohydrate as staple foods. The results showed that body weight was decreasing at desired level gradually. At the same time, insulin, cholesterol, TSH, and T4 levels remain well controlled without any intake of medications (Istek and Gurbuz 2017).

Diabetic Retinopathy An experimental study stated that anthocyanin 30 g as daily dose taken for 6 months by diabetic retinopathy subjects received a surprising benefit on ocular hypertension. According to Brigham Women's Hospital, personal communication, there is an association between blueberry intake and age-related macular degeneration and some efficacy in diabetic retinopathy but no relationship with postoperative cataract recovery (Calò and Marabini 2014).

Neurological and Cognitive In the United States, cohort studies were conducted on 1.5 lakh people with the daily intake of highbush blueberries that found lower Parkinson disease risk due to a strong relationship (highest quintile) to anthocyanin. Anthocyanin intake may also reduce the risk of Alzheimer's disease, attention deficit disorder, or dementia in geriatric people. Cognitive performance is a major concern to those senior people, children, and all students. They can have a high chance to improve memory power based on a minimum of 80 days or 12 weeks of daily consumption of blueberry (Whitmer et al. 2005; Krikorian et al. 2010).

Cognitive Function in an Older Adult A study pointed out that blueberry powder may help in cognitive development and subjective progress of brain among 39 older adults. They were having with cognitive complaints as per a research study. After 12 weeks of blueberries intake, significant progress of intelligence quotient was detected using MRI in healthy elderly adults (control group). Cognitive performance was analyzed among kids studying class I to class IV in a published study design where performance improved after 2 h of consuming a dose of one serving of powder but not placebo (Bowtell et al. 2017; Kalt et al. 2020).

Gut Microbiota Health benefits depend on gut microbiota, which play a mediator role in the transformation of phenolic compounds. Proper transformation can only bring good nutrition from blueberries. A study showed that bound and complex bioactive compounds underwent through the biotransformation in the small and large intestine by the gut microbiota and converted into the quick form for absorption (Anantharaju et al. 2016).

Limitation Short shelf life of blueberries can be a major issue, and for that long-time storage in the unfavorable environment should be avoided for the cause of deterioration of nutritional value. Proper management is needed for the collection of fruits from the farms due to the quick harvest season of fruits. Further, blueberries should be preserved for not more than 6 weeks in general, considering the dietary importance and actual health benefits (Almenar et al. 2008).

31.7 Conclusion

In the berries group, blueberries are very popular and most accepted because of multiple uses of fresh fruits as well as other forms, for example, juices, jelly, dried, cooking powder, etc. Blueberries are rich in bioactive compounds (BAC) along with fructose, glucose, water, dietary fiber, for example, pectin, cellulose, and hemicellulose. The phytochemicals in blueberries, for example, anthocyanins, chlorogenic acid, procyanidins, and other flavonoids are the key players to deliver the various health and nutritional benefits in a human body. The major contributor of antioxidant activity is anthocyanin (under flavonoids group), taking part of 84% of phenolic compounds. A 100 g edible portion of blueberries also contains malic acid, tartaric, fumaric, oxalic acid, and a good amount of ascorbic acid, folate and folic acid, which all together work as phytochemicals. The fruits are rich in a significant amount of magnesium, potassium, minerals and B vitamins in addition to the majority of multivitamins, PUFA, MUFA, and other essential and nonessential amino acids. They provide 57 kcal energy, 84.21 g of water, 14.49 g of carbohydrates, and 2.4 g dietary fiber per 100 gm of edible portion. Hence, blueberry is a potent antioxidant and immunity booster food choice of millions of people worldwide. This is not only a potent antioxidant but also a natural antidiabetic, antiaging, cardio-protective agent. They are very helpful for the good health of skin, eyes, bones, and cartilages apart from obesity and blood pressures management. In summary, “blueberries are superfoods” due to their potent antioxidant and immunity-boosting actions.

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Jamun

32

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Abstract

Jamun, scientifically known as *Syzygium cumini*, is a plant of dietary importance. Historic evidences show its therapeutic use in Ayurvedic medicines to cure several metabolic abnormalities. Jamun is a potential source of phenolic constituents distributed widely in all plant parts. These bioactive compounds include flavonoids, anthocyanins, carotenoids, dietary fiber, phenolic acids, and tannins, showing health beneficial effects. Ethnomedicinally, jamun is used as antioxidant, antihyperlipidemic, antiallergic, antihyperglycemic, hepatoprotective, anti-inflammatory, gastroprotective, nephroprotective, and antiarthritic. Both *in vivo* and *in vitro* studies have proved the neutraceutical, functional, and pharmaceutical importance of jamun. Thus, jamun, because of its associated phytonutrients is considered an ideal antioxidant fruit for the human consumption.

Keywords

Jamun · Bioactive compounds · Anthocyanins · Health benefits · Phytochemistry

Botanical name: *Syzygium cumini.*

Synonyms: *Eugenia jambolana* Lam, *Myrtus cumini* Linn, *Syzygium jambolana* DC., *Syzygium jambolanum* (Lam.) DC., *Eugenia cumini* (Linn.) Druce. and *Eugenia caryophyllifolia* Lam.

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Table 32.1 Various colloquial names of jamun in different languages

Language		Names
Indian	Assamese	Jamu, kala jamu
	Bengali	Kala jam
	Gujrati	Jambu, jaambu
	Hindi	Jamun, duhat, jam, jaman
	Kannada	Nerale hannu
	Konkani	Jambul
	Malayalam	Kaattucaampa, njaaval, njaara, perinjaara
	Manipuri	Gulamchat, jam
	Marathi	Jambool
	Mizo	Hmuipui
	Nepalese	Jamunu, phanrir
	Oriya	Jamkoli
	Pali	Jambu
	Prakrit	Jambulo, jammulo
	Punjabi	Jaman
	Sanskrit	Jambu, jambulah, meghamodini
	Tamil	Kottai-nakam, naval
	Telugu	Neredu
	Urdu	Jaman
Other	Brazil	Jambolão
	Burmese	Thabyay-hypyoo
	Europe	Black plum
	Filipino	Duhat, lomboi
	French	Jamélongue
	Javanese	Duwet, jamblang
	Khmer	Pring bai
	Malay	Jambolan, jambulana, jiwat, obah
	Nepali	Jamun
	Sinhala	Jambu, jambul, madan, naval
	Spanish	Jambolan
	Swahili	Msambarau, mzambarau
	Thai	Hakhiphae, wa
	Tibetan	Dzam-bu
	Vietnamese	Trâm môc, vôi rung

Adapted from Baliga et al. (2011), with some modifications

Common name: Jamun, Java Plum, Jambu, Jambolan, Black Plum, Danson Plum, Malabar Plum, Indian Blackberry, Portuguese Plum, etc. The other vernacular names of Jamun are enumerated in Table 32.1.

Taxonomic Classification:

Kingdom: Plantae

Sub-Kingdom: Tracheobionta
Infra Kingdom: Streptophyta
Super Division: Spermatophyta
Division: Magnoliophyta
Infra-Division: Angiospermae
Class: Magnoliopsida
Subclass: Rosidae
Order: Myrtales
Super Order: rosane
Family: Myrtaceae
Genus: *Syzygium*
Species: *cumini*

32.1 Introduction

Jamun (*Syzygium cumini* Linn.) is a nutritious fruit belonging to polyembryonic species of *Myrtaceae* family, indigenous to India, and naturalized in adjoining agro-climatic countries of Asian subcontinent, East African countries, southern America, Madagascar, and also cultivated in Florida and Hawaii regions of the United States (Mahindrakar and Rathod 2020). It is an evergreen wild tropical tree exhibiting enormous morpho-diversity, embraces almost 1100 species, and most widely known for its fruit (Ayyanar and Subash-Babu 2012). The other plant parts which include seeds, leaves, stem, root, and bark also have ethnomedicinal uses, especially in the traditional medicine (Díaz-Uribe et al. 2018). Jamun tree bears fruits in berry form and on the basis of morphological, geographical, and organoleptic characteristics; these berries are mainly divided into two morphotypes in India: the *Ras Jamun* and *Kaatha Jamun.* The *Ras Jamun* are oblong or ellipsoidal berries covered with dark purple to bluish skin, have sweet pinkish fleshy pulp, and small seeds; while the *Kaatha Jamun*, on the other hand, are small acidic berries (Baliga et al. 2011). Jamun is a fruit of high neutraceutical value because it contains an ample quantity of valuable nutrients such as carbohydrates, minerals, vitamins, and phytochemicals, which exhibit strong antioxidant property (Arya et al. 2018). However, the color and taste of the fruit is mainly attributed to anthocyanins and hydrolysable tannins (Chhikara et al. 2018a, b). Earlier epidemiological studies have reported that aqueous extracts of different parts of Jamun tree contain significant amount of secondary metabolites, organic acids, essential oils, and other non-nutritive compounds which possess tremendous therapeutic properties (Swami et al. 2012). The main bioactive compounds showing neutraceutical properties includes phenolic acids, flavonoids, anthocyanins, tannins, terpenes, carotenoids, saponins, fatty oils, and carbohydrates (Aqil et al. 2012). Moreover, the therapeutic characteristics of plant have been well noted in the literature, for example, a traditional healer for the treatment of diabetes (Ayyanar and Subash-Babu 2012).

32.1.1 Botanical Description

Jamun is a large, densely foliaceous evergreen tree with an apex of up to 100 ft. It has a huge canopy and maximum life span of over 100 years. The bark of the young jamun tree is grayish and thin but as the tree matures the color changes to darkish brown and becomes thick and scaly. Wood is whitish, durable, and grained with dyes (brown) and gum (Kino) (Ayyanar and Subash-Babu 2012. The 5–10 cm long, shiny, smooth, leathery, and turpentine smelling leaves vary in shape (usually oblong to elliptic) with pointed tips faced in opposite direction (Stephan 2012). The flowers are present at the stem tips in clusters of 10 to 40 covered with membranous petals, greenish-white in color, scented, small, and sessile. Jamun tree flowers annually and in India during the month of March to April (Baliga et al. 2011). Development of fruit starts in the month of May and ends in the month of June. The tree produces huge quantity of fruit usually in clusters of 5–20. During the initial stage, the color of the fruit is green and as the fruit matures it turns pink and then purple once the fruit is fully ripe (Chhikara et al. 2018a, b). Fully ripe fruits have mildly sour and astringent flavor, with a sweet taste and make our tongue purple, when eaten due to a pigment, anthocyanin (Swami et al. 2012). Apart from this, each fruit shows different variations in size and quality during the 2-month development process in terms of length, diameter, seed weight, and pulp percentage (Binita et al. 2017).

Generally, based on size, jamun has two types, the small one which are round, big-seeded, have little pulp, and sweet taste with high tannin and anthocyanin content; and the big one, that are oblong, small seeded, have more pulp and acidic taste with low tannin, acid, and anthocyanin content (Roy et al. 2013). However, in North India, the main type of variety grown is small-seeded, oblong, and purple-colored Raja jamun and another large-sized and without seeds called Paras jamun in Gujarat and Varanasi (Devi and Shenbagaveni 2014).

32.1.2 History and Distribution

Jamun has a long history of medical use especially in the traditional folk and Ayurvedic system of medicines for the treatment of diabetes and other associated complications (Warrier et al. 1996). All the plant parts especially bark is digestive and astringent and used for the treatment of asthma, sore throat, dysentery, bronchitis, and also is supposed to be useful for the healing of wounds. Jamun leaves are stated to be effective in denitrification, accounting for making gums and teeth strong (Baliga et al. 2011). Fruits are found to minimize surplus body heat, are hematinic and semen promoting, enhance and enrich blood, and also found to be liver tonic according to Siddha and Unani systems of medicine (Warrier et al. 1996). The tree is mostly found in the compounds of Hindu temples and is considered sacred by Hindus and Buddhists. During worship, the believers of Lord Ganesha (Elephant God) offer the leaves and fruits of this plant to him. Lord Krishna was also fond of this plant.

The annual yield of jamun fruit globally is 13.5 million tons. India, which ranks second accounts for about 15.4% in the total world production (FAO 2009). In India, jamun is mainly produced by the states of Maharashtra, Uttar Pradesh, Gujarat, Assam, and Tamil Nadu (Sagar and Dubey 2019). However, the state of Maharashtra is the leading producer of the fruit.

32.1.3 Nutritional Composition of Jamun

Jamun is considered a fruit of dietary importance and is highly nutritious. It is an excellent source of monosaccharides (glucose, fructose, and mannose) and disaccharides (sucrose, maltose, and galactose) (Al-Dhabi and Ponmurugan 2019), amino acids (asparagine, glutamine, alanine, cysteine, and tyrosine), fat-insoluble vitamins (ascorbic acid, thiamine, and niacin) (Ghosh et al. 2016), minerals, (calcium, sodium, potassium, phosphorous, iron, and zinc) (Raza et al. 2015), anthocyanins, and antioxidants (Devi and Shenbagaveni 2014). However, the exact nutritional composition of fruit and seed are listed in Table 32.2.

Table 32.2 Nutritional composition of Jamun fruit and seed

Parameter	Jamun fruit (Value per 100 g)	Jamun seed (Value per 100 g)
Energy (kcal)	60	380
Moisture (g)	77.2	52.24
Carbohydrates (g)	16.6	41.4
Protein (g)	0.70–1.4	6.3–8.5
Fat (g)	0.15–0.30	0.83–1.18
Fiber (g)	0.30–0.90	2.3–16.9
Antioxidants		
Ascorbic acid (mg)	5.70–18.00	0.21–1.84
Polyphenols (mg)	179.00–203.76	361.40–386.51
Anthocyanins (mg)	180.00–195.58	12.56–18.47
Tannins (mg)	94.52–297.50	388.99–428.75
Minerals		
Na (mg)	11.73	43.86
K (mg)	172.5	606.47
Ca (mg)	81.4	135.86
Zn (mg)	0.46	0.47
Fe (mg)	4.66	4.20
Mg (mg)	27.13	111.60
Cu (mg)	1.8	2.13
Mn (mg)	0.2	0.4
Pb (mg)	0.33	0.66
Cr (mg)	1.06	1.40

Source: Ghosh et al. (2016) and Chhikara et al. (2018a, b)

32.2 Characterization of Chemical Compounds Present in Jamun

Studies have reported that Jamun is rich in high value-added constituents having neutraceutical properties as functional ingredients. These include phenols, flavonoids, anthocyanins, alkaloids, tannins, saponins, terpenoids, phytosterols, and other biologically active compounds (Sartaj-Ali et al. 2013). Addition of food products with biologically active compounds has increased the interest to develop new functional foods for health-conscious consumers (Oliveira et al. 2016). However, the main bioactive ingredients present in the jamun plant (leaves, stem, flowers, roots, seeds, and fruits) are listed in Table 32.3. The antioxidant property exhibited by the bioactives help the body to scavenge active oxygen species and may therefore protect tissues against auto-oxidative damages, prevention from cancers, inflammation, and helps to boost immunity (Rafiq et al. 2018). Therefore, the intake of natural antioxidants from jamun is necessary for healthy life.

32.2.1 Phenolic Compounds

Phenols are the major bioactive compounds that have gained interest from the researchers, scientists, and food technologists due to their associated physiological functions. These micronutrients when present in the human diet prevents oxidative stress–mediated disorders like diabetes, cardiovascular dysfunctioning, neurodegenerative disorders, aging, and cancer by removal of free radicles and quenching active oxygen and nitrogen species (Huang et al. 2001; Perry et al. 2000; Hool 2006). Phenols, the secondary metabolites of the plant, are made up of an aromatic ring-bearing a single or more OH groups and mainly responsible for the organoleptic properties of colored fruits and their products (Chhikara et al. 2018a). They also act as substrates for enzymic browning reactions and include phenolic acids, flavonoids, lignans, tannins, stilbenes, and curcumins (Gordon et al. 2011).

Epidemiological literature has reported that jamun is an inexpensive source of polyphenols having protective health benefits such as antidiabetic, diuretic, antineoplastic, radioprotective, and chemoprotective (Srivastava and Chandra 2013). Total phenolic content of jamun pulp ranges from 2133.50 to 2250 mg GAE/100 g (Suradkar et al. 2017). Various phenolic acids have been isolated from the aqueous extracts of jamun including tannic acid, chlorogenic acid, gallic acid, caffeic acid, ellagic acid, methyl derivatives of ellagic acid (3,3-di-O-methyl ellagic acid and 3,3,4-tri-O-methyl ellagic acid), p-coumaric acid, ferulic acid, and betulinic acid in seeds, stem and bark, flowers, flesh, and leaves, respectively, constituting the main active phytochemicals of the plant (de Carvalho Tavares et al. 2016). Therefore, the presence of phenolics in fruits and vegetables can be regarded as biological makers to determine their quality especially during postharvest operations (Scalbert et al. 2005).

Table 32.3 Available functional ingredients in the plant

Part	Available bioactives	References
Leaves	Acylated flavonol glycosides, esterase, galloyl carboxylase and tannins, β-sitosterol, betulinic acid, mycaminose, crategolic (maslinic) acid, n-heptacosane, n-nonacosane, n-hentriacontane, n-octacosanol, n-triacontanol, n-dotricontanol, quercetin, myricetin, myricitrin and the flavonol glycosides myricetin 3-O-(4″-acetyl)-α-L-rhamnopyranosides	Sagrawat et al. (2006), Mahmoud et al. (2001), Bhatia et al. (1974)
	Essential oils: Pinocarveol, α-terpeneol, myrtenol, eucarvone, muurolol, α-myrtenal, cineole, geranyl acetone, α-cadinol and pinocarvone	Shafi et al. (2002)
Stem	Friedelin, epi-friedelanol, and fatty acid esters of friedelan-3-α-ol, betulinic acid, β-sitosterol, kaempferol, β-sitosterol-D-glucoside, gallic acid, ellagic acid, 11-O-galloylbergenin and ellagitannin, and myricetin	Bhatia and Bajaj (1975), Sagrawat et al. (2006)
Flower	Kaempferol, Oleanolic acid, ellagic acids, isoquercetin, quercetin, myricetin- (quercetin-3-glucoside), myrecetin-3-L-arabinoside, quercetin-3-D-galactoside, dihydromyricetin, acetyl oleanolic acid, eugenol-triterpenoid A and eugenol-triterpenoid B	Vaishnava et al. (1992), Sagrawat et al. (2006)
Root	Flavonoid glycosides, isorhamnetin 3-O-rutinoside	Vaishnava and Gupta (1990), Vaishnava et al. (1992)
Seed	Jambosine, gallic acid, ellagic acid, corilagin, 3,6-hexahydroxydiphenoylglucose, 1-galloylglucose, 3 galloylglucose, quercetin, β-sitosterol, 4,6 hexahydroxydiphenoylglucose, quercetin, 1–3, oenothein C, cornussin B, swertisin, valoneic acid dilactone, Brevifolin	Sagrawat et al. (2006), Rastogi and Mehrotra (1990)
Fruit	Raffinose, glucose, fructose, citric acid, mallic acid, gallic acid, anthocyanins (delphinidin-3-gentiobioside, malvidin-3-laminaribioside, petunidin-3-gentiobioside, cyaniding diglycoside, petunidin and malvidin)	Lewis et al. (1956), Jain and Seshadri (1975), Sharma and Sheshadri (1955)

32.2.2 Flavonoids

Flavonoids are a combination of hydroxylated secondary plant metabolites, ubiquitously present in all plant parts and mainly derivatives of 2-phenyl-benzo-γ-pyrone. The chemical skeleton of flavonoids consists of two benzene rings (A and B) linked by a 3-C heterocyclic pyran ring (C), referred as C_6–C_3–C_6 as shown in Fig. 32.1 (Panche et al. 2016). Based on oxidation level and substitution arrangement of pyran

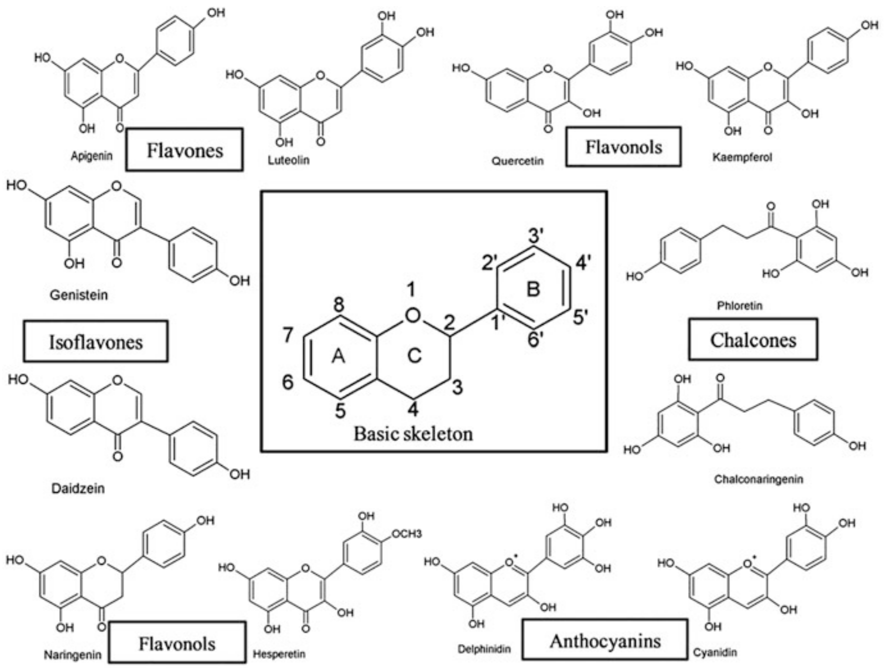

Fig. 32.1 Basic structure of flavonoids

ring (C), flavonoids are classified as isoflavones, flavonols, flavanones, flavones, flavan-3-ols, and anthocyanins (Havsteen 2002). Flavonoids are mainly responsible for influencing food quality and stability by acting as antioxidants, coloring, and flavoring agents (Kumar and Pandey 2013). It has been reported that jamun is rich in flavonoids such as quercetin, myricetin, kaempferol, as well as anthocyanins. The dietary intake of flavonoids has been known for their beneficial health impacts, both in vivo and in vitro, as a result of their high antioxidant properties such as anticancer, antimicrobial, and antidiabetes (Singh et al. 2016). Also, the occurrence of cardiovascular diseases is reduced due to their antioxidant properties. Jebitta and Allwin (2016) studied the phytonutrients present in the jamun pulp powder using various drying techniques. The results revealed freeze drying (−40 °C) to be the effective drying method with high antioxidant activity (70.4–75.8%), total flavonoid content (104.8 mg QE/g), and anthocyanin content (7.56 mg/g). Upon acid hydrolysis as detected by HPLC, five anthocyanidins namely peonidin (2.8%), cyanidin (6.6%), delphinidin (20.3%), petunidin (24.6%), and malvidin (44.2%), respectively, were also found in the powder (Aqil et al. 2012). The hydrolyzed pulp also showed antiproliferative activity.

32.2.3 Terpenes

Terpenes are fruit-based organic compounds, made of numerous isoprene units, and often determine the taste and flavor of fruits (Paduch et al. 2007). As a result of their characteristic odor, they are mainly used as natural fragrance and flavoring agents in food and pharmaceutical industries (Cho et al. 2017). Jamun is known to contain significant quantity of mono- and triterpenes (Jagetia 2017) such as α-pinene, pinocarvone, pinocarveol, α-cadinol, α-terpeneol, myrtenol, muurolol, myrtenal, cineole, eucarvone and geranylacetone in leaves, α-terpineol, β-terpinene, betulinic acid, β-pinene and eugenol in seeds, citronellol, geraniol, hotrienol, nerol, β-phenylethanol, phenylpropanal in fruit pulp; eugenol and oleanolic acid in flowers; and β-sitosterol, friedelin, and betulinic acid in stem bark (Sengupta and Das 1965). Terpenes show neuroprotective effects; prevent cancer cell formation; defend against fungal, viral, and microbial infection, and minimize the risk of inflammation (Sah and Verma 2011).

32.2.4 Carotenoids

Carotenoids are phytochemicals ubiquitously found in the nature. They are a class of isoprenoid molecules, mainly C_{40}, formed by conjugation of eight isoprene units. Carotenoids are present in both photosynthetic plants as well as non-photosynthetic species, such as bacteria and fungi, and are responsible for the yellow, orange, and red color of fruits and vegetables (F&Vs) (Saini et al. 2015). However, the characteristic color of carotenoids is attributed to the several (up to 15) conjugated C–C double bonds of the polyene chain. Carotenoids are mainly of two types, namely carotenes, which are cyclic or linear hydrocarbons, for example, α-carotene, β-carotene, lycopene, and oxycarotenoids, which are oxygenated hydrocarbons containing hydroxy, methoxy, carboxy, and epoxy groups, for example, xanthophylls, lutein, zeaxanthin, etc. (Prakash and Gupta 2014). The fruit of jamun is known to contain a carotenoid content of 48–50 mg/100 g (Suradkar et al. 2017). Major carotenoids present in jamun are lutein, β-carotene, zeaxanthin, β-cryptoxanthin, and lycopene. Due to their photochemical nature, carotenoids are responsible for quenching singlet oxygen by scavenging harmful free radical and reactive oxygen species (ROS), hence, act as antioxidants (Young and Lowe 2018). Numerous studies have revealed that carotenoid-rich foods show health beneficial effects due to their associated bioactive constituents such as minimized cancer risk, delay the process of aging, inhibit apoptosis, improve vision, and are used as neutraceutical, pharmaceutical, and cosmeceutical compounds (Prakash and Gupta 2014).

32.2.5 Dietary Fiber

Dietary fiber is that portion of the fruits and vegetables, cereals, and legumes which is resistant to enzymic digestion in the human intestinal tract. It includes both oligosaccharides and polysaccharides such as cellulose, hemicellulose, pectic substances, gums, mucilages, inulin, resistant starch, and also non-carbohydrate parts like resistant protein, polyphenols, waxes, and so on (Fuentes-Zaragoz et al. 2010). On the basis of their simulated gastrointestinal solubility, dietary fiber is mainly divided into soluble and insoluble dietary fiber. However, to be acceptable as a food ingredient, the ratio of soluble dietary fiber–insoluble dietary fiber (SDF/IDF) of any fiber source should be 1:2 (Jaime et al. 2002). Food and nutrition board has recommended an average daily intake of 20–26 g dietary fiber for females and 35–40 g for males (Food and Nutrition Board, Institute of Medicine 2001). So, dietary fiber supplementation can yield safer and economical food products with numerous health benefits. These compounds have both therapeutic properties, for example, enhance colonic fermentation, efficient fecal bulking, maintain blood glucose level, decrease pre-prandial cholesterol levels as well as functional properties like oil- and water-binding capacity, bile acid–binding capacity, viscosity and gel formation, stabilization of emulsions, and shelf life enhancement (Champ et al. 2003). Jamuns are rich in dietary fiber, which thus enables slow release of sugar in our bloodstream, keeping blood sugar in control (Muhammad et al. 2009). New data on the TDF, SDF, and IDF of jamun as 3.5 ± 0.02, 0.9 ± 0.02, and 2.6 ± 0.04, respectively, was provided by Punna and Paruchuri (2003), thus, playing an important role in human nutrition.

32.2.6 Volatiles and Other Bioactive Compounds

Volatiles or essential oils are natural aromatic organic compounds present in the flowers, leaves, buds, bark, wood, fruits, and roots of a plant. They are plant secondary metabolites, lipophilic in nature, and mainly composed of carbonyls, nitrogen, and sulfur compounds. Essential oils are formed via three metabolic pathways: methylerythritol pathway, for example, mono- and diterpenes; mevalonate pathway, for example, sesquiterpenes; and shikimic acid pathway, for example, phenylpropenes. These bioactive volatiles are diverse, mainly used as additives in food and pharma due to their antioxidant and antimicrobial effect and beneficial to human health due to their associated medicinal and therapeutic properties. Jamun plant is rich in essential oils, of which 82% is mainly concentrated in the leaves (Ayyanar and Subash-Babu 2012). The prominent essential oils present in jamun leaves are β-caryophyllene, guaiol, α-gurjunene, and aromadendrene (Mohamed et al. 2013). Jamun pulp essential oil was found to contain terpeneol, eucarvone, α-cadinol, myrtenol, geranyl acetone, α-myrtenal, and α-muurolol as major components (Singh et al. 2014). Of the stem essential oils camphene, α-pinene, β-pinene, cis-trans ocimene, bornyl acetate, myrcene, α-humulene, limonene, α-copaene, and δ- cadinene are found to be the major components. Chemical examination of the volatiles from the jamun leaves was conducted by Khanna (1991). The results revealed that a sweet raw mango–like aromatic odor comprising of 59% hydrocarbons was found while remaining being oxygenated derivatives. Major components were myrcene, β-pinene, γ-terpinene, terpinolene, β-phellandrene, and borneol (Sagrawat et al. 2006). The oxygenated derivatives were methyl cinnamate, cuminaldehyde, α-terpineol, eugenol, and borneol. Alpha-pinene, α-thujene, β-caryophyllene, nonyl alcohol, linalool, piperitone, safrole, and a sesquiterpene hydrocarbon giving positive test for azulenes were also identified (Khanna 1991).

Other bioactives in jamun plant are malic acid and citric acid (alkanes), phenylpropanoid like coniferyl alcohol, cinnamyl acetate, cinnamaldehyde, cinnamyl alcohol and linoleic acid, stearic acid, lauric acid, N-nonacosane and N-hentriacontane (lipids), among others (Arya et al. 2018).

32.3 Health Benefits and Potential Mechanisms of Action

Since antiquity, jamun was used for the treatment of several kinds of human disorders such as diabetes, diarrhea, cough, tinea, sore throat, and inflammation due to its medicinal, bioactive, and associated therapeutic properties. The fruit is known to show numerous pharmacological properties such as antihyperglycemic, antihyperlipidemic, cardioprotective, antimicrobial, anti-inflammatory, anticancer, radioprotective, antidiarrheal, gastroprotective, antiarthritic, and antihepatotoxicity (Table 32.4). The main relevant, validated, and beneficial pharmacological activities of jamun compounds are discussed below:

32.3.1 Anticancer

Cancer is defined as an abnormal or uncontrollable growth of cells leading to high rate of mortality every year (Sardana et al. 2018). Food products of natural origin has always been an excellent source of cancer drugs because of the numerous bioactive phytochemicals present in them like anthocyanins, flavonoids, proanthocyanidins, tannins, and phenolic acids (Baliga 2011). In vitro studies have shown the effect of jamun plant on the growth and apoptosis as well as cytotoxic activities of human cancer cell lines. Polyphenolic rich extracts of jamun play an important role in prevention of cancer by protecting against oxidative and carcinogen-induced DNA damage and modulation of signaling pathways involved with inflammation, cell cycle arrest, and cell proliferation (Kausar et al. 2012). A study conducted by Aqil et al. (2010) has shown chemotherapeutic effect of dietary Jamun on 17β-estrogen-mediated breast cancer cells as well as miRNAs role in disease inhibition. The results showed that incorporation of jamun diet delayed the appearance of tumor and compared to control, minimizes the tumor burden, tumor incidence, and tumor multiplicity. The diet was found to inhibit mammary cell proliferation (ER-α and cyclinD1) and growth of pituitary prolactinomas (prolactin, progesterone, and

Table 32.4 Various pharmacological activities of Jamun extracts and isolated compounds

Activity	Extract/ active compound	Model	Result	References
Antiulcer	Ethanolic extract	Mild diabetic rats	Decreased cholesterol, triglyceride, and glycosylated hemoglobin levels as well as reduced propensity to gastric ulceration caused by CRS, ASP, EtOH, and PL	Chaturvedi et al. (2007)
Anti-inflammatory	Methanolic and ethyl acetate leaf extract	Rats	Reduced carrageenan-induced paw edema	Jain et al. (2011)
	Ethanolic bark extract	Rats	Reduced the secretion of prostaglandin E2, serotonin and histamine	Muruganandan et al. (2002)
	Ethanolic leaf extract	Lethal sepsis-induced mice	Reduced systemic production of pro-inflammatory factors such as interleukin-5 whereas TNF-α and NO˙ production was decreased previous to inflammation induction	Maciel et al. (2008)
Hepatoprotective	Ethanolic pulp extract	Paracetamol-induced hepatotoxic albino rats	Decreased levels of serum marker enzymes, aspartate aminotransferase, alanine aminotransferase, and ALP; increased total protein and albumin content	Das and Sarma (2009)
	Methanolic seed extract	Carbon tetrachloride–treated rats	Reduced elevation of serum SGOT, SGPT, ALP, ACP and bilirubin levels.	Sisodia and Bhatnagar (2009)

(continued)

Table 32.4 (continued)

Activity	Extract/ active compound	Model	Result	References
Central nervous system activity	Ethyl acetate and methanolic seed extract	Albino mice	Significant decrease in spontaneous locomotor activity indicating central depressant effect	Kumar et al. (2007)
Antiviral	Leaf extract	Contagious diseases: Buffalo pox and goat pox	Increased inhibitory effect against all cytopathic effects	Bhanuprakash et al. (2007, 2008)
	Hot and cold aqueous leave and bark extract	Avian influenza (H5N1) virus	Significant virucidal activity (100% inhibition) against avian influenza virus (H5N1 serotype)	Sood et al. (2012)
Antimicrobial	Diethyl ether, methanol, water, acetone and ethyl acetate pulp extract	Gram-positive bacterial cultures: MTCC-430 *Bacillus cereus* (BC), MTCC-121 Bacillus subtilis (BS), MTCC-106 *Micrococcus luteus* (ML), and MTCC-435 *Staphylococcus epidermidis* (SE); and four gram-negative bacterial cultures, namely, MTCC-443 *Escherichia coli* (EC), MTCC-109 *Klebsiella pneumoniae* (KP), MTCC-735 Salmonella paratyphi (SP), and MTCC-734 Salmonella typhi (ST)	High inhibitory effect of diethyl ether followed by others.	Patel and Rao (2012)
	Methanolic and water leaf extract	Gram negative bacteria	Higher percentage of inhibition	Gowri and Vasantha (2010)

(continued)

Table 32.4 (continued)

Activity	Extract/ active compound	Model	Result	References
Nephroprotective	Active principle (FIIc) from aqueous pulp extract	Streptozotocin-induced diabetic rats	Significant fall in FBG levels.	Tanwar et al. (2010).
			Decreased urea, plasma creatinine level, urine volume, urine sugar and microalbuminuria.	
Anti-arthritic	Methanolic seed extract	Fruend's complete adjuvant-induced arthritic rats	Improved red blood cell count, hemoglobin level, and erythrocyte sedimentation rate indicating progress in arthritis and recovery from anemic conditions	Kumar et al. (2008)
Radioprotective	Ethanolic seed extract	γ-Radiation treated mice	Increased expression of DNA polymerase beta gene due to myricetin. Thus, increasing mice survival. Ellagic acid inhibit radiation-induced lipid peroxidation	Abalea et al. (1999), Theresiamma et al. (1996)
Anti-diarrheal	Ethanolic bark extract	Diarrheal rats	Significant inhibition of defecating frequency and wetness of fecal droppings.	Mukherjee et al. (1998)

estradiol levels). Both overexpressed and underexpressed MiRNAs were significantly protected by dietary jamun. Thus, Jamun dose at 5% (w/w) significantly cause reduction in estrogen-associated mammary carcinogenesis. However, the mechanism involved in causing tumorogenesis is complex involving two pathways. First is the hormone receptor-associated cell proliferation and second is the metabolism in which hydroxylated metabolites induce mutations causing carcinogenesis. In another study, Li et al. (2009) reported the effect of standardized extract of Jamun fruit as antiproliferative and pro-apoptic on the estrogen-mediated (MCF-7aro) and estrogen-independent (MDA-MB-231) mammary cancerous cells. Results have shown that jamun fruit extract was most effective against estrogen-dependent

MCF-7aro at IC50 of 27 μg/m followed by estrogen independent MDA-MB-231 at IC50 of 40 μg/m breast cancer cells, showing significant dietary effect of jamun extract against breast cancer. Extracts of jamun, thus, acquires potent anticancer activity against various cancer cell lines (Li et al. 2009). Anthocyanins, the water-soluble pigments have been found to be mainly responsible for the antitumorigenic properties such as apoptosis, metastasis, and cancer cell proliferation (Aqil et al. 2012). The synergistic effect of anthocyanins such as malvidin, peonidin, petunidin, cyanidin, and delphinidin is responsible for the antiproliferative activity by modulating different molecular targets that involve DNA repair genes, transcription factor, and principle pathways (Bcl-2, Cyclin D1, Notch, COX-2, P13/AKT) and also some metastatic and angiogenic mediators uPAR, VEGF, and MMPs (Bagchi et al. 2004). However, the other polyphenols such as flavonols, phenolic acids, and ellagitannins in the extracts of jamun were also known to possess chemoprotective, antioxidant, and anticarcinogenic properties. Ellagic acid, a potent anticarcinogenic agent, was also found to be effective against colon, skin, breast, and prostate cancers via direct or indirect mechanisms (Aiyer and Gupta 2010). Anticancer mechanism of ellagic acid include induced apoptosis, prevention of metastasis, inhibition of DNA damage and drug resistance proteins, antiviral activity, and radio sensitization.

32.3.2 Antihyperlipidemic

Hyperlipidemia is a medical disorder characterized by an abnormal increase in the blood lipid profile. Alterations in the lipid level causes heart stroke, atherosclerosis, and neurodegenerative and cardiovascular disorders (Ravi et al. 2005). Clinical studies have shown jamun berry extracts to possess a potent antihyperlipidemic activity. Sharma et al. (2008) revealed that the flavonoid-rich extract of jamun seed lowers the LDL and triacylglycerol levels while it raises the HDL- levels in albino mice. The results were in conformity with Ravi et al. (2005). Administration of jamun seed extract in streptozotocin-induced diabetic rats minimized the LDL and VLDL serum cholesterol levels while as increased HDL levels mainly by regulating the uptake and hydrolysis of lipoproteins and metabolic activity in plasma, liver, and kidney. The antihyperlipidemic activity of jamun extract is mainly attributed to inhibition of 3-hydroxy-3-methyl-glutaryl-CoA which is responsible for the production of cholesterol (Ravi et al. 2005). Flavonoids present in jamun accounts for this activity and works by increasing cAMP-dependent phosphokinase expression. This enzyme acts by inhibiting HMG-CoA reductase (Havsteen 2002). Such effects might be also due to the lowered absorption of cholesterol by intestines as well as increased free fatty acid and triacylglycerol clearances subsequent to insulin action improvement (Sharma et al. 2012). Both the activity and expression of microsomal hepatic lipoproteins are controlled by ethanolic extract of jamun leaf which is further controlled by insulin signaling pathways. Also, quercetin, a flavonoid found in the jamun plant, is known to prevent adipogenesis by downregulation of transcriptional factors and lipases in OP9 rat stromal cells (Seo et al. 2015).

32.3.3 Antioxidant

It is well known that free radicles, active oxygen, and nitrogen species initiate the development of various human ailments, namely, neurodegenerative and cardiovascular diseases (Alia et al. 2008). Free radicals have also been reported to cause diabetic complications via numerous pathways. These include glucose autooxidation, protein glycation, with subsequent formation of advanced glycosylation end products and increased glucose flux via sorbitol–aldose reductase (polyol) pathway (Oberley 1988). Antioxidants are the cardiometabolic agents that quench these radioactive species and improve the antioxidant defense mechanism (Valko et al. 2007). Literature from the past have reported jamun to be rich in antioxidants due to the presence of neutraceutical constituents. The protective effect of Jamun seed extract to prevent auto-oxidative stress among the Swiss albino mice was reported by Arun et al. (2011). The authors found that oral feeding of jamun seed extract to mice exposed to carcinogens urethane and 7,12-dimethylbenzanthrance showed minimum damage to chromosomes caused by oxidative stress. Further, biochemical analysis of liver samples showed progressive inhibition in lipid autooxidation while improving glutathione levels and associated enzymatic activity of superoxide dismutase, glutathione S-transferase, and catalase (Arun et al. 2011). Ravi et al. (2004) evaluated the effect of jamun seed extract on plasma and pancreatic antioxidant defense system in streptozotocin-induced diabetic rats. Results showed that jamun seed extract incorporation in diabetic rats reduced the levels of blood glucose and thiobarbituric acid reactive substances in both the tissues. The decreased levels of ascorbic acid and glutathione and increased levels of vitamin E, catalase, ceruloplasmin, superoxide dismutase, and glutathione peroxidase which were returned back to acceptable levels after the injection of jamun seed extract in diabetic rats. Further, histopathological analysis proved that jamun seed extract in diabetic rats restored the altered structure of both tissues. Bioactive compounds, as antioxidants, in jamun reduce the oxidative stress by depleting active oxygen species and lowering the concentrations of hydro and lipid peroxides. In another study, Aqil et al. (2012) evaluated the antioxidant potential of jamun pulp and seed extract by 2,2-diphenyl-1-picrylhydrazyl (DPPH), oxygen radical absorbance capacity, 2,2-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid and fluorescence recovery after photobleaching (FRAP) assays. Results showed that both the extracts have high antioxidant potential. The strong antioxidant activity of both jamun seed and pulp is mainly attributed to its phytochemical composition especially anthocyanidins and ellagitannins present in the extract. The methanolic and methylene chloride extracts of the jamun leaf and its essential oils were evaluated for the antioxidant activity using DPPH and FRAP assays (Mohamed et al. 2013). Methanolic extracts were reported to have high antioxidant and antibacterial activity than methylene chloride and essential oil extract. Gas chromatography mass spectrometry (GC-MS) analysis showed that jamun leaf extract contains tannins such as α-pinene and β-pinene, accounting for their antioxidant activity and their potential application in functional food and neutraceuticals.

32.3.4 Antidiabetic

Diabetes is a metabolic disorder associated with increased blood sugar levels in the body. The incidence of this disease is increasing rapidly throughout the world, having overall prevalence of about 6% around the globe with Type II diabetes constituting about 90% Ramachandran et al. 2002. Diabetes is becoming third killer of humans after cancer and cardiovascular diseases. Current antidiabetic therapies involve the use of various agents having side effects in the human body. So, there is a need to explore antidiabetic agents that are safe and therapeutically efficient with little or no side effects. Various researches have been done to identify different components in fruits responsible for antidiabetic properties. Due to the presence of bioactive components like flavinoids, essential oils, oxalic acid, gallic acid, betulic acid, etc. in different parts including leaves, seeds, and pulp, jamun (*Syzygium cumini*) is considered to possess a number of health benefits including antidiabetic effect. Jamun has been traditionally used in ayurvedic medicines to treat diabetes by taking about 10 ml of juice extracted from ripe jamun fruits thrice a day. Katiyar et al. (2016) suggested that dried fruits of jamun when extracted with hot water are used to treat diabetes. Many medical systems prescribe jamun seeds to control diabetes like diseases, as it has been studied that jamun seeds possess a phytochemical constituent called as mycaminose. Various studies suggest that whole seed of jamun shows moderate lowering in glucose levels in the body whereas seed coat does not show any hypoglycemic effect, suggesting that the major bioactive constituents with hypoglycemic effect are present in kernel. Both aqueous and methanolic extracts obtained from jamun seed, bark, leaves, and roots reduce serum glucose levels in alloxan-induced diabetes in rats. Jamun seed contains both aqueous soluble and insoluble fibers. Aqueous soluble fiber, unlike the aqueous insoluble fiber, is known to possess hypoglycemic property Teixeira et al. 2004. Khan and Burney (1962) studied that hot water extracts of aerial parts of this plant when taken by adults (500 mg) shows antidiabetic effects. Achrekar et al. (1991) suggested that extract obtained from jamun pulp stimulates the secretion of insulin in the body. Some studies suggested that increase in insulin content on consumption of jamun was due to the conversion of pro insulin into insulin by cathepsin enzymes in the body. Different scientists suggested probable mechanism of action of jamun but the proper mechanism of jamun lowering the glucose levels in the body is not known yet.

32.3.5 Cardioprotective Property

Cardiovascular diseases are considered as number one killer disease of humans worldwide. Different parts of jamun possess the cardioprotective property. Doxorubicin-induced cardiotoxicity in rats was prevented by ethanolic extract obtained from jamun seeds when administered at a concentration of 500 mg/kg for 30 days. Taking about 5 g of jamun seed powder for about 3 months twice daily before meals results in decrease in blood pressure (Sidana and Singh 2016).

Herculano et al. (2014) showed that jamun leaves when extracted with a hydro-alcohol, result in decrease in both blood pressure and heart rate by promoting extracellular calcium influx and decrease in arterial tone.

32.4 Conclusion

Jamun is a rich source of nutrients and is widely used in the traditional system of medicine for the treatment of various human ailments, especially diabetes. The disease-preventing properties of jamun is mainly attributed to the amount of phytonutrients present mainly anthocyanins, phenolic acids, flavonoids, and tannins. Among all the biofunctional constituents, anthocyanins contribute to the color while as tannins are responsible for the sour and astringent taste. Various in vitro studies of different parts of the jamun such as fruit, leaf, stem, bark, seed, and root have been commercialized as food or herb to ameliorate inflammation, hyperglycemia, hyperlipidemia, and so on. Keeping in view its bioactive composition and neutraceutical properties, jamun has wide applications in food, pharma, and in the formation of nanoparticles, natural dyes and adsorbents for the removal of pollutants. Rich in antioxidants, jamun can be used as value-added food supplements, providing advantageous polyphenols and dietary fiber. Thus, the significant potential of underutilized jamun as a functional food is increasingly being recognized.

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