Gulzar Ahmad Nayik
Amir Gull *Editors*

# Antioxidants in Vegetables and Nuts - Properties and Health Benefits

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*This book is dedicated to my late grandparents & great grandfather Hakeem Mohammad Ismail Damsaaz*

# Preface

The production and consumption of vegetables have expanded dramatically in the last decade primarily due to presence of high amount of vitamins, minerals, dietary fiber, and phytochemicals. Vegetables make up a major portion of the humans diet and are critical for good health. Higher vegetable consumption reduces the risk of diseases from diabetes to osteoporosis to diseases of the gastrointestinal tract, cardiovascular diseases, autoimmune diseases, and cancer. Nuts are nutrient-dense foods with complex matrices rich in unsaturated fats, high-quality protein, fiber, minerals, tocopherols, phytosterols, and phenolic compounds. Various chronic diseases like hypertension, cancer, inflammation, oxidative stress, blood pressure, coronary heart disease, etc., are positively influenced by nut consumption. Studies have proved that people who avoid vegetable and nut consumption or consume in very little are indeed at increased risk of these diseases. Therefore, interest in the health benefits of vegetable and nut consumption is increasing.

In order to improve vegetable and nut consumption, it is necessary to know and understand their nutritional and nutraceutical profile. This book provides a comprehensive knowledge about the nutritional and nutraceutical profile of a wide range of popularly consumed vegetables and nuts.

The editors have designed this book for college students, university scholars, researchers, food scientists, olericulturists, dieticians, and agricultural scientists. Members of vegetable and nut processing industries, horticultural departments, and other agricultural departments will also find the comprehensive information relevant to their work.

Shopian, Jammu and Kashmir, India — Gulzar Ahmad Nayik
Srinagar, Jammu and Kashmir, India — Amir Gull

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**Gulzar Ahmad Nayik** is currently working as Assistant Professor (Cont.) at the Department of Food Science & Technology, Govt. Degree College, Shopian, J&K, India. He completed his Masters Degree in Food Technology at IUST, Awantipora, India and his PhD at SLIET, Punjab, India. He has published over 40 peer-reviewed research / review papers, several book chapters, and one textbook. Dr. Nayik was shortlisted twice for the prestigious INSPIRE-Faculty Award in 2017 and in 2018 from INSA New Delhi. Dr. Nayik was nominated for India's prestigious National Award (INSA Medal for Young Scientists-2019-20). Dr. Nayik is also an Editor, Associate Editor, Assistant Editor & Reviewer for many journals, and a member of various associations like WASET, AFSTI, IFERP, IAJC, ASR, ACSE etc. He is a recipient of the Top Peer Reviewer Award 2019 from Web of Sciences.

**Amir Gull** is currently working as a Senior Research Fellow at the Department of Food Science & Technology, University of Kashmir, Srinagar, J&K, India. He completed his Masters Degree in Food Technology at Islamic University of Science & Technology, Awantipora, J&K, India and his PhD at 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, together with several book chapters. Dr. Gull's main research activities include developing functional food products from millets. In addition to serving as an editorial board member and reviewer for several journals, he is an active member of the Association of Food Scientists and Technologists India. He is also a recipient of the MANF from UGC India.

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# Part I

# Vegetables

# Pea

# 1

Jasmeet Kour, Gulzar Ahmad Nayik, Raees ul Haq, Naveen Anand, Mohammed Shafiq Alam, Breetha Ramaiyan, Renu Sharma, Nowsheen Nazir, and Swapan Banerjee

**Abstract**

Pea is a nutritious leguminous crop widely cultivated across the globe, with the potential to withstand freezing temperatures. With 10.53% area under production, India occupies fourth position in area under pea cultivation and 5$^{th}$ in pea production (6.96%). It is one of the most significant agricultural commodities owing to its numerous health benefits. It is utilized in soups, pastas, health foods, breakfast cereals, and processed meats apart from being processed in the form of flour, starch, and pea protein concentrates. Pea seeds also contain pivotal nutrients such as proteins, carbohydrates, vitamins, minerals, as well as fiber. The non-nutrient compounds comprise phenolics such as flavonoids, condensed tannins, and

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simple phenolic compounds in high concentration primarily in the varieties having seed coats with dark color. There is a dearth of data regarding the phenolic profile of pea seed coats, with the available data confined to a few varieties only. The fiber present in the seed coat as well as the cell walls of the cotyledon maintain the gastrointestinal health and functioning as well. The peel or the seed coat of peas strengthens not only the chemical but also physical barrier mechanism of the seeds as well as act as potential cancer-preventive agents.

**Keywords**

Pea · Flavonoids · Tannins · Health benefits · Antioxidant activity

## 1.1 Introduction

**Botanical name/Common name-** *Pisum sativum* (L.)/Garden pea

### 1.1.1 History

*Pisum sativum*, commonly known as *garden pea/field pea*, pertaining to family *Leguminosae* has proven to be a boon to ecology owing to its immense contribution in fixation of nitrogen present in the atmosphere as well as serving as a break crop, diminishing the need for external intake (Smykal et al. 2012).

The ancestral origin of this crop is in the Middle East, which subsequently extended toward Europe and North America as well (Barzegar et al. 2015). The wild species *Pisum fulvum* of the genus *Pisum* originated in Lebanon, Jordan, Syria, and Israel, whereas the cultivated species such as *Pisum abyssinicum* find their origin in Yemen and Ethiopia (Ellis et al. 2011). Food and Agriculture Organisation (FAO) has also referred Ethiopia along with western Asia as one of the prime locations of peas diversity, whereas Mediterranean region and South Asia have been designated as the secondary centres (Department of Agriculture, Forestry & Fisheries, South Africa).

*Pisum sativum* is one of the most ancient domesticated crops (Zohary and Hopf 2000). The consumption of peas dates back to 9500 years, and cultivation dates back to 8500 years (Elzebroek and Wind 2008). The ancient Greek as well as the Roman writers mentioned this crop, but the varieties got acknowledged after the sixteenth century (Simmonds 1976). The widespread cultivation of peas is prevalent in temperate zones (Maxted and Ambrose 2001; Zohary and Hopf 2000). Western Asia has been the first area of cultivation of peas from where it extended to Europe, China, and India. It is one of the most prominent legumes which is cultivated across the globe (Salunkhe and Kadam 1999).

Mature and ripened seeds which are used as unbroken or as dal are utilized in various ways for human consumption. Peas are either grown as single or in combination with cereals to be utilized as green fodder as well as silage (Elzebroek and

Wind 2008). Due to their rapid growth and nitrogen contribution to the soil, these are cultivated in the form of green manures and crops which are meant for enriching the soil (Ingels et al. 1994). The consumption of peas is also prevalent as roasted, boiled, and split dal in some parts of the world (Aggarwal et al. 2015).

### 1.1.2 Production (India, World)

The production of *Pisum sativum* is mainly prevalent at higher altitudes in temperate regions in cold weather in the world (Elzebroek and Wind 2008). Pea peel is considered as a significant agricultural waste (Rehman et al. 2015). The annual production of pea was 57,000 tons in 2010–2011 (Pakistan economics survey 2010). The first cultivation of peas took place in Western Asia followed by Europe, China and India (Department: Agriculture, Forestry & Fisheries, South Africa). Yellow field peas are prominently grown in western Canada, which makes Canada as one of the leading exporters in the world (Wang et al. 2003). Peas can be grown on various types of soils out of which fertile sandy loam soils which are well irrigated are considered the best one for the crop. Globally, pea ranks third most prominent pulse crop after dry bean and chickpea. Along with this, it is also positioned at the third place in terms of the most significant rabi pulse of India after chickpea and lentils. One of the most important global commodities is the yellow field pea seed (Pulse Canada 2009). In 2007–2008, Canada held the top-most position in production and export of dry pea stock, with a credit of around 30% production on annual basis in the world (Agriculture and Agri-Food Canada 2009).

There is an extensive consumption of peas (*Pisum sativum* L.) and broad beans (*Vicia faba* L.) in the entire world, with a production of 8.3 and 3.6 million tons of peas and broad beans in 2008, respectively (http://faostat.fao.org/site/567/default.aspx#ancor). The by-products of these two legumes were approximated to be 67% and 70%, respectively (Basterrechea and Hicks 1991). The harvesting process has been estimated to produce 5.6 and 2.4 MT of by-products of pea and broad bean, respectively. These by-products generated from several agro-industries can be promising ingredients to serve as functional or bioactive components (Mateos-Aparicio et al. 2012). Pea mainly grows in the temperate climatic regions, being consumed in the form of either a legume or vegetable across the globe in order to satisfy human consumption and animal fodder as well (Upasana and Vinay 2018).

The most prominent pea-producing countries are India, France, Russia, Canada, China, and United States of America (Food and Agriculture Organization 2012). As far as the United States of America is concerned, peas are grown primarily in Montana, North Dakota, and Washington (USDA-National Agricultural Statistics Service 2011). India holds the second place in the world in the production of vegetables, with credit of 40 million tons and area of 4 million hectares (Singla et al. 2006). India occupies an area of 10.53% and production is 6.96% which gives it 5th rank in pea prodution in the world (FAO Stat. 2014). The major pea-producing state in India is Uttar Pradesh, which alone produces about 49% of pea produced in India along with Bihar, Madhya Pradesh, and Maharashtra as the other major pea-producing states (DES, 2015–2016). In India, the area under green peas increased at a constant rate from 1,777,000 hectares in 1991–1992 to 2,726,000 hectares in 1999–2000, respectively (Singla et al. 2006).

India stands next to China as far as the production of green peas is concerned (Adeyeye 2002). It is a salient leguminous crop in the world. The origin of this crop was in the Middle East, followed by its cultivation in North America along with Europe. FAO statistics has reported that in the year 2013, the green pea production in the world was 18.5 million tons approximately (Safaryan et al. 2016). The prominent countries leading in green pea production are India, the United States, China, France, and Algeria (FAO 2016). According to historical Roman and Greek authors, the cultivation of this crop was primarily carried out for serving as a pulse and a fodder crop (Department: Agriculture, Forestry & Fisheries, South Africa).

Peas and other leguminous crops are utilized in crop rotations owing to the fact that they help in improving soil microbe diversity, breaking up pest cycles, providing nitrogen, improving soil assemblage, and in the conservation of soil and providing economic diversity as well (Chen et al. 2006). There are various types of peas which are meant for serving various purposes. The harvesting of garden peas is done before the seed attains maturity for fresh-pack market (Elzebroek and Wind 2008). The inner pod fiber is absent in snow peas as well as in sugar snap peas, and they also undergo harvesting prior attaining maturity for fresh-pack market (McGee 2012). In countries like Africa, garden pea and sugar pea are regarded as exotic plants, with the former consumed more in Anglophone countries whereas the latter more in Francophone countries (Department: Agriculture, Forestry & Fisheries, South Africa).

The production of green peas has significantly enhanced to 3.20 million tons in 2003–2004 from 1.30 million tons in 1991–1992 (www.fao.org). In 2008, around 8.3 million tons of peas were produced in the world. Peas (*Pisum sativum* L.) have widespread consumption and production all over the world (FAO Statistical Yearbook 2014). Peas can be grown on all kinds of soils, except heavy soils, with an optimum pH range of soils ranging between 6.0 and 7.5 and temperature for optimum germination of peas is 18–22 °C, whereas seed germination decreases at temperature of 25 °C and above (Singh and Dhall 2018).

Pea is a significant cool-season and nutritious leguminous vegetable that has widespread cultivation in the entire world. As of now, this crop is seen in all temperate countries as well as in most tropical highlands (Department: Agriculture, Forestry & Fisheries, South Africa). In India, the cultivation area occupied by peas is 459,000 hectares, which makes it up to 21% production of the world, out of which Punjab being the fifth in pea production in India and accounts for 6.7% of India's production (Singh and Dhall 2018).

### 1.1.3 Botanical Description

*Pisum sativum* is a perennial member of the legume family (Fabaceae) (Aggarwal et al. 2015). It is a leguminous crop having a taproot system with lean, hollow, and succulent stem (Department of Agriculture, Forestry & Fisheries, South Africa). It is an annual vine with a soft appearance which can go up to 9 feet long. The stem of the pea plant is hollow one and anchoring is required to climb the taller cultivars (Elzebroek and Wind 2008). The flowers exhibiting various colors ranging from white, red, or purple undergo the process of self-pollination, with cylindrical pods comprising 5–11 seeds (Department of Agriculture, Forestry & Fisheries, South Africa). The top-most petal, the two petals smaller in size in the center which are fused together, and the two petals in the bottom are referred as a "standard," "keel," and the "wings," respectively (Elzebroek and Wind 2008). The shape of the ripened or mature pea seeds can be round or wrinkled and exhibit wide variations in color ranging from red, yellow, green, beige, blue-red, dark violet, to black (Pavek 2012).

Botanically, it is categorized as a fruit-bearing seeds developed from the ovary of the flower with a life span of 1 year (Saha et al. 2014). Garden peas being erect have a plant height of 30 cm, whereas field peas having a tendency to climb can be of a height of 75 cm (Department of Agriculture, Forestry & Fisheries, South Africa). Despite the fact that it is botanically a fruit, yet it is utilized as a vegetable for cooking purpose (Aggarwal et al. 2015). Garden pea bears white flowers and seeds can be round or wrinkled with their seed color as green or yellow, whereas field pea (*Pisum sativum* var. *arvense*) bears purple or other colored flowers with round seeds (Singh and Dhall 2018).

## 1.2 Antioxidant Properties and Characterization of the Chemical Compound(s) Responsible for Antioxidant Properties

Plants are regarded as one of the most valuable sources of natural antioxidants, mainly comprising the compounds which belong to the class of end product of secondary metabolism, including a handful of phenolic compounds (Stanisavljevic et al. 2015). Legume seeds are also nutritionally dense in starch, protein, dietary fiber, fatty acids, and micronutrients (Troszynska and Ciska 2002). The chemopreventive action of legumes has been acknowledged as the driving force for the analysis of their bioactive compounds and their action mechanism which could act as a boon in cancer research (Stanisavljevic et al. 2016). Due to ever-increasing interest in the consumption of food-derived antioxidants, thorough investigations are being carried out in order to explore the antioxidative value of legumes and beans as well (TroszynHska et al. 2002).

There are various bio-active compounds such as polyphenols present in the seed coat which act as potent antioxidants protecting against oxidative damage (Osawa et al. 1985). Over the years, the phenolic contents as well as the antioxidant profile of raw and processed pea seeds have been extensively studied (Han and Baik 2008). These polyphenolics exhibit tremendous reducing power as well as free-radical scavenging activity which makes the by-products of legumes such as broad beans and peas a sustainable source of valuable ingredients (Mateos-Aparicio et al. 2011). There is no dearth of the literature highlighting the phenolic and other antioxidative compounds present in pulse hulls (Amarowitcz et al. 2005; Troszynska and Ciska 2002). The antioxidative potential of pea grains and pea pods is reported to be due to various amino acids as well as ring compounds (Saha et al. 2014).

It is the seed coats which play a major part to strengthen the chemical and physical barrier system of the seeds as they get exposed to oxidative deteriorative phenomena such as oxygen, ultraviolet light, and various other environmental factors (Chaudhary et al. 2015). The seed coats of peas are embedded with rich polyphenolic compounds, which have led to their vast exploitation (Innocentini et al. 2009) as well as ensuring cost-effective way for their utilization (Stanisavljevic et al. 2016).

Many studies have highlighted the chemopreventive and therapeutic values of seed coats of peas verified on animal models (Sanchez-Chino et al. 2015). The hulls of peas and lentils have been well evaluated for total phenolic content (TPC) as well as in vitro antioxidant potential (Oomah et al. 2011). The antioxidative values of pea hulls are attributed to flavones, flavonols, and pro-anthocyanidins whereas flavonoid catechin is responsible for the antioxidative value of cotyledon of pea (Duenas et al. 2006). The seed coats of peas are enriched in condensed tannins such as hydroxybenzoic and hydroxycinnamic acids besides luteolin, flavonols, flavones, apigenin, quercetin, kaempferol, and stilbenes (Stanisavljevic et al. 2016).

Matscheski et al. (2006) analyzed the escalation of cells apart from the synthesis of progesterone in trophoblast tumor cells and concluded that seeds of both the green and yellow pea exhibited high levels of isoflavones apart from promising phytoestrogens that have the potential to reduce in vitro multiplication and production of progesterone in trophoblast tumor cells.

Mateos-Aparicio et al. (2010) evaluated the polyphenolic content of broad bean pods and pea pods and reported that the extractable polyphenols were significantly greater in former (30.8/kg) than in latter (4.2/kg). However, the antioxidant activity measured as ferric reducing antioxidant power (FRAP) was also significantly greater in pods of broad bean than pea. The polyphenols extracted also exhibited high reducing power and free-radical scavenging attribute.

Aggarwal et al. (2015) investigated the antioxidant activity of the ethanolic extract of *Cajanus cajan and Pisum sativum* determined by FRAP method. The maximum antioxidant power (5.86 μM) in peas was shown by ethanolic extract at a concentration of 25 μg and increased with the increase in extract weight. Duenas et al. (2004) reported the presence of phenolics prevalent in the seed coats of two pea varieties bearing dark color. The major compounds detected in the seed coat were glycosides of flavones, tetrahydroxy dihydrochalcone, flavonols, and hydroxybenzoic acids. It was also observed that the composition of the seed coats produced a huge impact on the phenolic profiles.

In a significant study by Amarowicz and Troszyñska (2003), extraction of phenolic compounds and tannins from pea seeds was done with aqueous acetone (80) and water–acetone (1:1; v/v) as mobile phases (Table 1.1). The antioxidant and antiradical characteristics of the phenolic compounds in extract were evaluated. The major phenolic compounds detected in the crude extract were *p*-coumaric, caffeic, ferulic, quercetin, vanillic, sinapic acids, and kaempferol. Total antioxidant activity

**Table 1.1** Various phenolic compounds and their content in crude extract of peas

| Phenolic compounds | Content [mg/g] |
|---|---|
| Vanillic acid | 0.07 |
| Caffeic acid1 | 0.02 |
| *p*-Coumaric acid1 | 0.06 |
| Ferulic acid1 | 0.32 |
| Sinapic | 0.07 |
| Quercetin2 | 0.14 |
| Kaempherol2 | 0.51 |
| Procyanidin B2 | 3.85 |
| Procyanidin B3 | 3.22 |

Source: Amarowicz and Troszyñska (2003)

of tannin fraction, extract, and fraction I came out to be 2.48, 0.30, and 0.22 μmol Trolox/mg, respectively. Fraction II exhibited the highest total phenolics (113 mg/g).

Stanisavljevic et al. (2015) investigated the phenolic content of seed coats in four varieties of pea with different colors (*Pisum sativum* L.). The compounds detected were hesperetin, rutin, galangin, naringin, rosmarinic acid, and pinocembrin along with 10 flavonol glycosides. The maximum antioxidant activity and total phenolic content were exhibited by genotypes MBK 168 and MBK 173 having dark color. The antioxidant activities as well as the amino acid profile of peptide fractions of a pea protein hydrolysate were evaluated. Higher contents of hydrophobic apart from aromatic amino acids were observed in the fractions that eluted later from the column in comparison to the ones that eluted early (Pownall et al. 2010).

Saha et al. (2014) conducted a chromatography technique for the analysis of *Pisum sativum*, which reported that both the pea pod and pea cotyledon comprised of equal amounts of antioxidants and bioactive compounds. In the evaluation of antioxidant potential of spinach, peas, and sweetcorn, Bajcan et al. (2013) estimated the highest antioxidant activity in sweet corn (0.970 mmol Trolox/g), whereas the lowest activity was found out in peas. On the contrary, the total polyphenol content was found the highest in spinach (285.1 mg GAE/kg), whereas peas exhibited the lowest one.

In a pivotal work, pea peels, flaxseed, and aloe vera peels were analyzed for their antioxidative properties. The total phenolic content, total flavonoid content, and antioxidant activity was exhibited at the highest level by flaxseed at extraction temperature of 60 °C, ethanol concentration (70%), and extraction time of 120 min and at pH 4–6. Similarly, pea peels were reported to exhibit the highest total phenolic content, total flavonoid content, and antioxidant activity at methanolic concentration of 90%, extraction time of 75 min, extraction temperature of 40 °C and pH 2–4, whereas aloe vera peels exhibited maximum total phenolic content, total flavonoid content, and amino acid content at methanolic concentration (90%), extraction time, extraction temperature, and pH of 60 min, 60 °C, and pH 8, respectively (Chaudhary et al. 2015).

Hadrich et al. (2014) identified the antioxidant as well as antimicrobial components of pea peel. The total phenolic content, total flavonoid content of peel

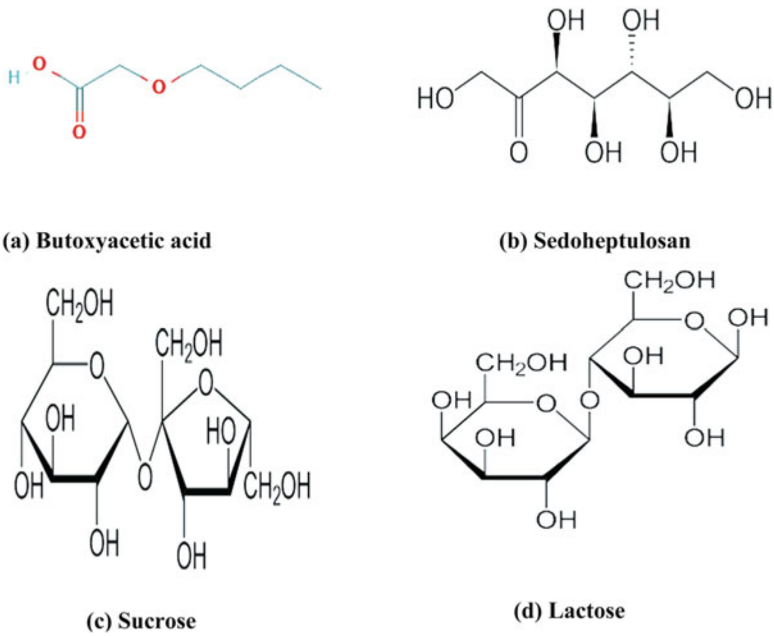


**Fig. 1.1** Compounds reported in grains of *Pisum sativum*. (Source: Saha et al. 2014)

extract of peas, aqueous extract, methanolic extract, and ethyl acetate extract as well was evaluated to estimate the antioxidative value. It was reported that the ethyl acetate extract exhibited the highest antioxidant activity. The total polyphenolic content, total flavonoid content, and antimicrobial activities of crude aqueous extract, a methanolic extract, and an ethyl acetate extract were evaluated. The antioxidant potential of the extracts was reported to be fairly high.

Saha et al. (2014) evaluated the antioxidant potential of *Pisum sativum* and found a wide range of bioactive compounds in pod as well as cotyledons (Figs. 1.1 and 1.2). There is less work reported on the phenolic compounds which impart anticarcinogenic and antioxidant properties to pea seed coat extracts. The anticarcinogenic potential of the extracts of pea seed coat and in vitro cytotoxic activity was evaluated on selected human was described by the method of Singleton and Rossi (1965).

The antibacterial activities of skin and seeds of *Pisum sativum*, juices of leaves and stem of *Mentha piperita*, and skin and pulp of *Momordica charantia* were evaluated for various species of Gram-negative bacilli: *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Salmonella typhi*, *Salmonella paratyphi A*, *Salmonella paratyphi B*, *Proteus mirabilis*, *Proteus vulgaris*, *Enterobacter aerogenes*, *Shigella dysenteriae*, and *Yersinia enterocolitica*. The highest antibacterial activity was exhibited by leaves of *M. piperita* while the stem was reported to have least antibacterial activity. A fairly high level of antibacterial

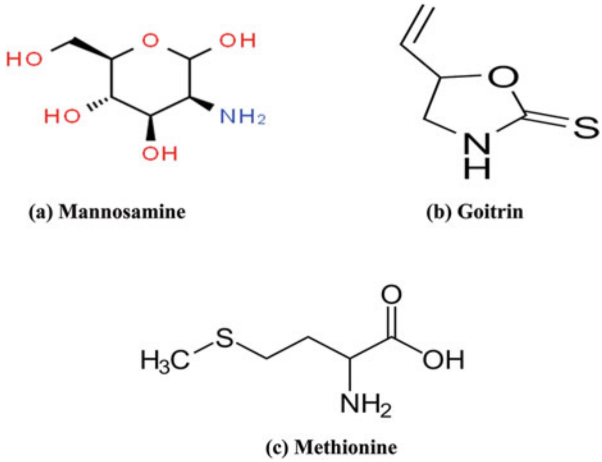


**Fig. 1.2** Compounds reported in pods of *Pisum* sativum. (Source: Saha et al. 2014)

activity was reported by skin and seeds of *P. sativum* as well as skin and pulp of *M. charantia* (Saeed and Tariq 2005).

The phytochemical profile including the antioxidant activities and antimicrobial activities of peas extracts prepared with *Debaryomyces hansenii* were analyzed. Flavonoid content was detected at low level whereas the antioxidant and antimicrobial activities was high. The remarkable antibacterial and antifungal potential of the fatty acid extracts of peas inhibited several microbes. The extracts were reported to be less effective against *Escherichia coli*, *Staphylococcus aureus*, and *Candida albicans*. The fatty acid extract of peas prepared with *Debaryomyces hansenii* inhibited the growth of *Bacillus megaterium* and *Escherichia coli*. The peas extracts containing *Debaryomyces hansenii* also exhibited antifungal activity (Erecevit and Kirbag 2017).

## 1.3 Health Benefits

In accordance with history, *Pisum sativum* has been an integral component of the diet of human beings owing to their cheap cost, ready availability, and high nutritional constitution (Martens et al. 2017). The protein content and starch content of peas varies between 15.5–39.7% and 36.9–48.6%, whereas amylase content is 34% of seed weight in peas. The two main limiting amino acids in peas are methionine and cystine. Fresh and frozen form of peas are an adequate source of pivotal vitamins such as thiamine (vitamin $B_1$), ascorbic acid (vitamin C), folic acid along with protein and fiber as well (Erecevit and Kirbag 2017). These are also the storehouse of biologically active ingredients that impart health and therapeutic effects primarily decrease in LDL-cholesterol and prevention of degenerative diseases like coronary heart disease and various types of cancer (Roy et al. 2010). The various significant nutritional requirements are supposed to be met by the extract obtained from pea owing to high amount of dietary fiber and other nutrients

**Table 1.2** Nutritional value of garden pea (per 100 g fresh weight basis)

| Nutrient | Value |
|---|---|
| Energy | 81 Kcal |
| Protein | 5.4 g |
| Carbohydrates | 14.5 g |
| Dietary fiber | 5.1 g |
| Fat | 0.4 g |
| Vitamin A equiv. | 38 μg |
| Beta-carotene | 449 μg |
| Lutein and zeaxanthin | 2593 μg |
| Thiamine (Vit. B1) | 0.3 mg |
| Riboflavin (Vit. B2) | 0.1 mg |
| Niacin (Vit. B3) | 2.1 mg |
| Pantothenic acid (Vit. B5) | 0.1 mg |
| Vitamin B6 | 0.2 mg |
| Folate (Vit. B9) | 65 μg |
| Vitamin C | 40.0 mg |
| Calcium | 25.0 mg |
| Iron | 1.5 mg |
| Magnesium | 33.0 mg |

Source: Dahl et al. (2012)

(Mateos-Aparicio et al. 2010). Peas with high fiber content is also an abundant source of prebiotics (Erecevit and Kirbag 2017).

The nutritive value of pea is very high, comprising of carbohydrates; fats; digestible proteins; pivotal minerals such as calcium (Ca), phosphorus (P), and magnesium (Mg); and vitamins such as A, B, and C (Dahl et al. 2012) (Table 1.2). These are an inexpensive source of essential amino acids such as tryptophan and lysine, soluble and insoluble fiber, complex carbohydrates, vitamins and minerals like iron, potassium, and calcium, as well as overall digestible nutrients (86–87%) without sodium as well as fat content (Tiwari and Singh 2012). Apart from this, these are also abundant in sulfur-rich amino acids (Wang et al. 2003).

The protein content of peas varies between 15% and 35% with high level of the essential amino acids such as tryptophan and lysine (Elzebroek and Wind 2008). There is an ever-increasing demand for pea starches and flours to be utilized in extruded food products, crackers, frozen foods, cookies, and soups as well. In addition to high quality protein, starch, vitamins, minerals, and dietary fiber, peas also comprise of numerous phytochemicals and bioactive compounds safeguarding health (Martens et al. 2017).

Yellow field peas also serve as a great storehouse of protein isolates, starches, fiber ingredients apart from abundant source of protein, starch, vitamins, and minerals which can be of immense aid in designing health and diet foods (Agboola et al. 2010). The amino acid profile of pea proteins can be fairly compared to that of other legumes (Iqbal et al. 2006). The gastrointestinal health and fiber of the seed coat contribute heavily in the starch digestibility in peas. The transitional amylose potential of starch in pea is reported to be credited for lowering down the glycemic index as well as digestibility of starch (Dahl et al. 2012).

The by-products obtained from broad beans and peas are some of the richest sources of insoluble dietary fiber and moreover they are also rich in arabinogalactans, galactans, xylo-oligosaccharides, and other oligosaccharides (Mateos-Aparicio et al. 2012). Other pivotal sources of dietary fiber powders are carrot pomace, orange waste, peels of potato, and green pea (Sharoba et al. 2013).

### 1.3.1 Health Effects of Pea Hull Fiber

During 2008, peas produced around 67% of the by-products (Basterrechea and Hicks 1991), yielding around 5.6 million tons of by-products which played an outstanding role as functional ingredients from agro-industries (Mateos-Aparicio et al. 2011). Pea peels are produced enormously as a waste to be utilized in the form of cattle feed (Babbar et al. 2014). The by-products of peas are known to be potentially abundant source of insoluble dietary fiber (Mateos-Aparicio et al. 2010). Due to the presence of significant nutrients and dietary fiber, the various functional components in this crop have been acknowledged to serve as a prominent source of food additive (Mateos-Aparicio et al. 2010). The fiber of the pea hull is composed of dietary fiber along with polyphenols and isoflavonoids, which help in curbing cardiovascular and other chronic diseases related to metabolic disorders such as diabetes (Martens et al. 2017).

Pulse hulls comprise maximum proportion (89%) of the dry matter forming dietary fiber derived from natural origin (Dalgetty and Baik 2003). Pea hulls constitute soluble and insoluble dietary fibers, with former in less proportion than the latter (Martens et al. 2017). Fitzpatrick (2007) acknowledged the beneficial effects of pea hull fiber on the health of the intestines in elderly persons. The excellent bulk, bland taste, low energy content, and fermentation tendency in pea hull have been reported to influence the fiber content in dietary patterns of human beings (Martens et al. 2017). The pods of green pea are also a great source of waste material of biological origin along with the polysaccharides obtained from them paves the way for the production polysaccharide of natural origin (Safaryan et al. 2016).

Pea hull fiber has its utilization in food as well as in feed industry to a considerable extent. In addition, it also finds its expansive usage in technological applications by improving fiber content in bakery products, pasta, and sausage production as well (Singh et al. 2008).

## 1.4 Conclusion

*Pisum sativum* is one of the most pivotal sources of proteins for both humans as well as animals. It is acknowledged as an integral part of human diet owing to rich nutrient profile, ready availability, and cost-effectiveness. Pea peels are also an abundant storehouse of active ingredients acting as antioxidants such as phenols and flavonoids. These peels are primarily utilized in the production of various value-added products and animal feed. The fibrous part of hull is a promising source of dietary fiber delivering various functional attributes. In addition to this, peas are also well known for imparting protection against free radical scavenging by virtue of the phenolic compounds. These pea polyphenols have significant reducing power as well. Much work has been cited in the literature so far exploring antiradical and antioxidative value of pea seeds.

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# Lotus (*Nelumbo nucifera* Gaertn)

2

Anu Pandita and Deepu Pandita

**Abstract**

*Nelumbo nucifera* Gaertn ($2n = 16$) (Nelumbonaceae), also known as the Sacred Lotus is an imperative perennial plant of aquatic habitat renowned for its prominent, beautiful, and magnificent flowers with diverse colors and owning nutritional and medicinal significance. Lotus of Asian countries are in shades of pink to pure white. Many bioactive chemical constituents mainly alkaloids, terpenoids, flavonoids, and phenolics have been identified in lotus. The medicinal principles relating to phytochemical and pharmacological activities mainly include antioxidant potential. In recent times, attention has mounted significantly in finding antioxidants from natural sources for utilization in foods or medicines. Because of the appraisal of antioxidant activity of plants as medicine, *Nelumbo nucifera* Gaertn which is very significant against damage triggered by the free radicals within a cell and reactive oxygen species (ROS) in a living being was explored for the antioxidant prospective of flowers, receptacles, leaves, seeds, and rhizomes. This chapter aims at understanding the antioxidant properties of different plant parts (leaves, flowers, receptacle, seeds, and rhizomes) of *Nelumbo nucifera* Gaertn, phytochemistry of its various bioactive compounds over and above alkaloids, flavonoids, glycosides, triterpenoids, etc., and the benefits derived from these phytoconstituents.

**Keywords**

Lotus Stem · Antioxidant activity · Reactive oxygen species · Pharmacological activity · Phytochemistry

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## 2.1 Introduction

**Botanical Names**
*Nelumbo nucifera* Gaertn
*Nymphaea nelumbo* Linn

**Common Names**
**English:** Lotus, Oriental Lotus, Bean of India, Hindu Lotus, Sacred Lotus, East Indian Lotus, Egyptian Bean, Sacred Water Lily, Sacred Water Lotus, Baladi Bean, Lotus Bean, Water Lotus, Indian Lotus, Egyptian Lotus, Chinese Water Lily
**Hindi:** Padam, Kamala, Kamal, Lalkamal, Kanwal, Ambuj, Kamal-Kakri

*Nelumbo nucifera* Gaertn (Sacred Lotus; $2n = 16$) is a significant economic and medicinal aquatic plant, which has irreplaceable cultural and religious importance for Buddhists and Hindus and belongs to a small plant family of Nelumbonaceae that is currently kept in the mono-generic Nymphaeaceae family (Duke et al. 2002; Wang and Zhang 2005), with a solitary genus Nelumbo, which further contains two species namely, Asian Lotus/Indian lotus or *Nelumbo nucifera* Gaertn (found throughout Asia in China, India, Australia, and Russia) and American Lotus/Water chinquapin or *Nelumbo lutea* Pers. (Eastern and Southern North America) (Mukherjee et al. 1996a, b; Williamson and Schneider 1993; Sayre 2004).

The fossil records disclose that 15 million years ago there were eight *Nelumbo nucifera Gaertn* species at global level (Wang and Zhang 2005; You 1998). In Asia, the lotus is under cultivation for more than 7000 years for its edible seeds, leaves, rhizomes, and beautiful flowers (Yang et al. 2012; Kubo et al. 2009; Shen-Miller 2002; Ming et al. 2013). The lotus seeds with extraordinary longevity remain viable for 1300 years and lotus rhizomes stay vigorous for above 50 years and shows remarkable property of water repellency, well known as the Lotus Effect because of nanoscopic narrowly packaged distensions of its self-cleaning surface of leaf (Shen-Miller et al. 2002; Shen-Miller 2002). The parts of lotus plant like flowers, androecium, pollens, rhizomes, stems, and leaves are both used as food/vegetables and a part of indigenous system of medicine in China as well as India (La Cour et al. 1995; Anonymous 1992; Mukherjee et al. 2009; Sridhar and Bhat 2007). The different parts of Lotus like buds, leaves, roots, stalks, rhizomes, flowers, and fruits have been employed as plant-based drugs for cure against diseases of hypertension, cancers, diarrheal problems, cardiovascular issues, depression, and insomnia (Shen-Miller et al. 2002; Duke et al. 2002). Antioxidant potential of lotus plant parts, for example, leaves (Wu et al. 2003), roots (Jung et al. 2011; Ham et al. 2017), stamens (Jung et al. 2003), and lotus rhizomes (Cho et al. 2003; Hu and Skibsted 2002) is well recognized. Leaves of lotus plant have diverse antioxidant chemicals like ascorbic acid, phenolic compounds, carotenoid compounds, flavonoid compounds, and tocopherol compounds (Choe et al. 2011).

*Nelumbo nucifera* Gaertn has various vernacular and botanical names. Indian *Nelumbo nucifera* Gaertn is recognized as the *Padma* and/or *Kamala* which has two plant varieties, commonly called the *Pundarika* or *Sveta Kamala* (white lotus variety); and the *Rakta Kamala* (pink or reddish pink lotus variety) (Chopra 1958). All the parts of lotus plant have a distinctive name and almost all the parts have medicinal value, providing one or more drugs (Raghunath and Mitra 2005). The whole lotus plant along with the flower is well known as *Padmini*, the rhizomes of lotus as *Kamalkand* (Nadru in Kashmiri), the leaves of lotus as *Sambartikai*, the peduncle of lotus as *Mrinal* or *Visa*, the stamens of lotus as *Kirijalika*, the receptacle of lotus as *Padma Makaranda* or *Padma-Madhu*, Padmakosa, seeds of lotus as *Karnika* or *Padmaksya* (Pambuch in Kashmiri), and honey of lotus flowers is known as *Makaranda* or *Padmamadhu* (Anonymous 1982). Ming et al. (2013) sequenced the lotus genome of the Chinese traditional variety with estimated 929 Mbp genome size. A lotus root which is a popular vegetable known as Nadru in Kashmiri has antianxiety, antifungal and anti-inflammatory activities (Du et al. 2010).

### 2.1.1 Origin and History

Lotus was in existence since 135 million years in the aquatic environment of Northern Hemisphere. This plant was bestowed with honor in history by countries like India, China, and Egypt (Karki et al. 2012, 2013; Harer 1985), wherein flower of lotus can be appreciated in their traditional art, culture, and religion. Lotus is admired in Australia Pacific, China, India, Korea, and Japan (Harer 1985; Anonymous 1992). *Nymphaea caerulea*, commonly known as the Sacred Blue Lotus, showed distribution sideways the banks of River Nile (Harer 1985; Anonymous 1966) along with lotus. Egyptians, Hindus, and Buddhists worship lotus. Egyptians worshipped the flowers, fruits, and sepals of lotus plant. After Egypt, lotus was transferred to region of Assyria and extensively planted throughout Indian, Persian, and Chinese regions. Lotus is common in Australian, Chinese, Indian, Iranian, and Japanese regions. From China, lotus was introduced to Japanese region and subjected to cultivation for over 1000 years. In China, lotus is grown as a crop with industrial value on above 40,000 hectares of land. In India, lotus is pervasive, and established in Himalayan lakes as well (Sridhar and Bhat 2007). Lotus is the "National Flower of India." It is sacred and symbol of purity and sanctity. The garlands made from the white or mainly pink flowers are used for the decoration and worship of Goddess Lakshmi as a "symbol of wealth" in temples (Mehra et al. 1975). Lotus was under cultivation in the Far East since 5000–7000 years (Wong 1987); by way of proof of cultivation of lotus plant from $>$3000 years for utilization as food, drugs, and in events of cultural and religious significance (Shen-Miller 2002). Sir Joseph Banks (1787) initiated horticulture of lotus plant in Western Europe as stove-house water lily. Today, lotus plant is prevalent virtually ubiquitously in plant herbal and botanical garden collections.

### 2.1.2 Distribution and Production (India, World)

*Nelumbo nucifera* Gaertn – the lotus is native to China, Japan, and India. The natural distribution of Lotus extends from Japan to northeast Australia and across the Caspian Sea. Lotus is extensively dispersed throughout the Caspian Sea to the Asian zone. Lotus is widespread in a range of countries like North Australia, China, Iran, Korea, and Malaysia (Lim 2016). Guo (2009) put on records that *Nelumbo* is extensively cultivated throughout Indian continent because of the belief of being a sacred plant by the Hindu religion. It is distributed throughout India and extends up to northwest Himalaya, Kashmir, West Bengal, central and southern Bihar, Orissa, Maharashtra, south India, and northeast India (Assam, Manipur, and Mizoram, etc.). In India, it grows in ponds, lakes, and tanks. *Nelumbo nucifera* Gaertn is grown in China, Japan, and India in terraced fields and in Indian country due to its fragrant flowers, seeds, fruits, and rhizomes (Anonymous 1966). The propagation of lotus is done by seeds and rhizomes in March to April mainly in ponds, and rhizomes are ready to harvest in October. Flowering takes place during hot and rainy seasons and seeds ripen toward the end of rains.

### 2.1.3 Botanical Description

**Taxonomic Classification**
(Mukherjee et al. 1996a, b)

| | |
|---|---|
| **Kingdom:** | Plantae |
| **Sub Kingdom:** | Tracheobionta |
| **Super Division:** | Spermatophyta |
| **Division:** | Magnoliophyta |
| **Class:** | Magnoliopsida |
| **Subclass:** | Magnoliidae |
| **Super order:** | Protaenae |
| **Order:** | Proteales |
| **Family:** | Nelumbonaceae/Nymphaeaceae |
| **Genus:** | Nelumbo |
| **Species:** | *Nelumbo nucifera* Gaertn. |

### 2.1.4 Nutritional Value

The leaves, rhizomes, and stems of *Nelumbo nucifera* Gaertn are appetizing and can be prepared as vegetables (Anonymous 1992) or pickled and served with syrup (Phillips and Rix 1995). The lotus corolla find use in soups and garnishes, whereas the lotus stamens as added as tea additive (Ibrahim and Eraqy 1996). Lotus seeds can be used as popcorn, powdered, or eaten dry while the roasted seeds act as coffee substitute (Ling et al. 2005). Lotus known as Nadru in Kashmir is profoundly correlated with its culture and economy. Nadru-based cuisines like lotus stem and yoghurt curry (Nadru yakhni) stem rogan josh, stem-palakh, stem kabab, stem pickles, stem fish, etc. are an integral part of every Kashmiri religious, social, and/or cultural occasion. The nutritive value analyses of raw lotus plant parts done in the United States report the proximate composition per 100 g value as given in Table 2.1.

## 2.2 Antioxidant Properties and Phytochemistry of *Nelumbo nucifera* Gaertn

Biological action of phytochemicals is related with their antioxidant prospective (Dey et al. 2016). The scientific investigations on the antioxidant activities of various lotus parts are highest, equaling to 18 in in vitro and 8 in in vivo conditions. Yet, no single index is believed to be adequate for determination of the entire antioxidant capability (Feng et al. 2016; Venkatesh and Dorai 2011; Karadag et al. 2009), owing to variety in reaction of chemical constituents (Lopez-Alarcon and Denicola 2013). According to Feng et al. (2016), inconsistencies are present in the outcomes acquired from embryos of different cultivars of lotus through the use of 2, 2-diphenyl-1-picrylhydrazyl (DPPH) and Ferric Reducing Antioxidant Power (FRAP) assays. Hitherto 12 phenolics and 89–90 flavonoids (out of which 47 were flavonols, 25–26 were flavones, 8 were flavan-3-ols, 4 were flavanons, and 5 were anthocyanins) were reported from leaf pulp of lotus, veins of lotus leaves, stalk of lotus leaves, receptacle of lotus, epicarp of lotus, coat of lotus, kernel of lotus, embryo of lotus, androecium, flower petals, gynoecium, and stalk of lotus plant. The seeds (Rai et al. 2006), leaves (Huang et al. 2010), rhizomes (Yang et al. 2007), and stamens (Hyun et al. 2003) of lotus plant exhibit antioxidant actions. Jung et al. (2003) anticipated that the OH at the carbon-3 locations structurally adds to the antioxidant property of flavonoids present in the stamens of lotus plant. When a glycoside hides the OH at the carbon-3 loci, half maximal inhibitory concentration ($IC_{50}$) values reduce severely. Kaempferols have excellent antioxidant activities in 2, 2-Diphenyl-1-Picrylhydrazyl, peroxynitrite scavenging activity (PSA), and overall reactive oxygen species; while kae 3-GlnPyr-methylester and kae 3-GlnPyr illustrated slighter scavenging properties in DPPH and PSA. Kae 3-GluPyr and Kae 3-GalPyr show activity merely in the assay of peroxynitrite scavenging activity (Jung et al. 2003). Hyun et al. (2006) observed analogous outcome for $IC_{50}$ antioxidant rates of isorhamnetin glycosides in male reproductive part of lotus. The glycosylation affects antioxidant ability, solubility of aglycones, and the stability of aglycones (Zhu et al. 2017). The flavonoids of lotus with C-glycosides present in the embryo of lotus demonstrate high in vitro antioxidant capability compared to O-glycosides (Zhu et al. 2017). Polyphenols possess antioxidant activity responsible for many health advantages (Lee et al. 2012; Devkota et al. 2015). The antioxidant activities of phenolic acids are directed by their chemical structures. The antioxidant activity of phenols enhances with the increase in number of hydroxyl groups (Moure

**Table 2.1** Nutritive value of lotus root and lotus seeds, raw per 100 g

| Nutrient | Root {amount} | Seeds {amount} | Unit |
|---|---|---|---|
| Ash | 0.97 | 1.07 | g |
| Calcium, Ca | 45 | 44 | mg |
| Carbohydrate, by difference | 17.23 | 17.28 | g |
| Energy | 74 | 89 | kcal |
| Energy | 311 | 372 | kJ |
| Fiber, total dietary | 4.9 | | g |
| Protein | 2.6 | 4.13 | g |
| Total lipid (fat) | 0.1 | 0.53 | g |
| Water | 79.1 | 77 | g |
| Copper, Cu | 0.257 | 0.094 | mg |
| Folate, DFE | 13 | 28 | μg |
| Folate, food | 13 | 28 | μg |
| Folate, total | 13 | 28 | μg |
| Iron, Fe | 1.16 | 0.95 | mg |
| Magnesium, Mg | 23 | 56 | mg |
| Manganese, Mn | 0.261 | 0.621 | mg |
| Niacin | 0.4 | 0.429 | mg |
| Pantothenic acid | 0.377 | 0.228 | mg |
| Phosphorus, P | 100 | 168 | mg |
| Potassium, K | 556 | 367 | mg |
| Retinol | 0 | 0 | μg |
| Riboflavin | 0.22 | 0.04 | mg |
| Selenium, Se | 0.7 | | μg |
| Sodium, Na | 40 | 1 | mg |
| Thiamin | 0.16 | 0.171 | mg |
| Vitamin A, IU | 0 | 13 | IU |
| Vitamin A, RAE | 0 | 1 | μg |
| Vitamin B-6 | 0.258 | 0.168 | mg |
| Vitamin C, total ascorbic acid | 44 | 0 | mg |
| Zinc, Zn | 0.39 | 0.28 | mg |
| Fatty acids, total saturated | 0.03 | 0.088 | g |
| 14:0 | 0 | 0.001 | g |
| 16:0 | 0.028 | 0.077 | g |
| 18:0 | 0.001 | | g |
| Fatty acids, total monounsaturated | 0.02 | 0.104 | g |
| 16:1 | 0.002 | 0.062 | g |
| 18:1 | 0.014 | 0.012 | g |
| 20:1 | 0.002 | 0.031 | g |
| Fatty acids, total polyunsaturated | 0.02 | 0.312 | g |
| 18:2 | 0.014 | 0.285 | g |
| 18:3 | 0.006 | 0.027 | g |
| Alanine | 0.054 | 0.239 | g |
| Arginine | 0.088 | 0.338 | g |

(continued)

**Table 2.1** (continued)

| Nutrient | Root {amount} | Seeds {amount} | Unit |
|---|---|---|---|
| Aspartic acid | 0.369 | 0.505 | g |
| Cystine | 0.022 | 0.054 | g |
| Glutamic acid | 0.139 | 0.957 | g |
| Glycine | 0.156 | 0.221 | g |
| Histidine | 0.038 | 0.115 | g |
| Isoleucine | 0.054 | 0.205 | g |
| Leucine | 0.069 | 0.326 | g |
| Lysine | 0.094 | 0.264 | g |
| Methionine | 0.022 | 0.072 | g |
| Phenylalanine | 0.047 | 0.206 | g |
| Proline | 0.136 | 0.344 | g |
| Serine | 0.06 | 0.252 | g |
| Threonine | 0.051 | 0.2 | g |
| Tryptophan | 0.02 | 0.059 | g |
| Tyrosine | 0.029 | 0.1 | g |
| Valine | 0.055 | 0.266 | g |

**Source:** United States Department of Agriculture Agricultural Research Service (2019). Food Data Central: Food and Nutrient Database for Dietary Studies with Standard Reference Legacy Release-169250 and 16859. Retrieved 10-03-2020. www. *fdc.nal.usda.gov*

et al. 2001). The seed gallic acid which has 3-hyroxyl (OH) groups showed higher antioxidant potential than caffeic and chlorogenic acid which have 2-hyroxyl groups and p-hydroxybenzoic acid having 1-hyroxyl group (Yen et al. 2005). The polysaccharides also show scavenging action and reduction property of leaf extracts of this plant, besides phenolic acids and flavonoids (Zhang et al. 2015). The seeds of lotus plant encompass alkaloids, saponins, phenolic acids, and carbohydrates which possess a great degree of antioxidant activity (Mukherjee et al. 2010a, b).

### 2.2.1 Antioxidant Properties and Phytochemicals Present in Fruit/Receptacle of *Nelumbo nucifera*

Various scientific investigations are available on the separation and identification of the chemical compounds present in the receptacle of lotus plant. Ling et al. (2005) improved, characterized, and scrutinized the antioxidant potential of procyanidins of *Nelumbo nucifera* Gaertn receptacle. With mass spectroscopy, Ling et al. (2005) inferred presence of huge concentrations of dimers than monomers and tetramers of catechin and epicatechin procyanidins in sample extracts. The natural polyphenols in seedpod of lotus signifies its source as antioxidants. Wu et al. (2013) isolated and verified five diverse flavonol glycosides in receptacle of lotus plant out of which hyperoside and isoquercitrin were antioxidants. Hu (2005) analyzed the nutritive value and antioxidant capability of lotus receptacle wherein they obtained and identified quercetin-3-*O*-β-D-glucopyranoside – a dietary flavonoid in lotus.

The receptacle of lotus plant contains judicious but noteworthy magnitude of key secondary metabolites which are phenolics. Phenolics exhibit a variety of bio-pharmacological effects in conjunction with antioxidation (Ling et al. 2005), such as improvement in learning ability and memory proficiencies (Gong et al. 2008), protection from experimental myocardial wounds and ischemic disorders (Zhang et al. 2004), radio protecting action (Duan et al. 2010), and antitumor effects (Duan et al. 2004). The quantity of total phenolic acids ranged from 255.65 to 477.61 mg/g, flavonoid compounds ranged from 353.31 to 540.84 mg/g, and pro-anthocyanidins ranged from 112.41 to 358.42 mg/g which are responsible for antioxidant capability of receptacle of lotus extract in 11 diverse cultivars of China. The methods used for their estimation were DPPH, 2,2′-Azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) diammonium salt, superoxide anion radical scavenging, reducing power, activities of antioxidation, metal chelation, and β-carotene bleaching. In DPPH free radical scavenging activity ($IC_{50}$), the entire phenolic acid content ($r = 0.9529$) showed positive correlation (Zheng et al. 2012).

### 2.2.2 Antioxidant Properties and Phytochemicals Present in Seed of *Nelumbo nucifera* Gaertn

The linoleic acid, an unsaturated fatty acid, was mainly copious at 0.285 g/100 g of seeds of lotus plant (Lim 2016). The annexin proteins and a myriad of natural compounds which function as antioxidants were reported in seeds of lotus (Chu et al. 2012). Three alkaloids, known as neferine, liensine, and isoliensinine, were efficaciously separated and identified from seeds of *Nelumbo nucifera* Gaertn through liquid chromatography (Chen et al. 2007). Liu et al. (2009) furthermore reported analogous results from crude extracts of embryos of lotus seeds. Besides, other major secondary metabolites, Mehta et al. (2013) reported dauricine alkaloid, roemerine alkaloid and pronuciferine alkaloid from the seeds of lotus plant. Diverse flavonoids, for example, rutin, Syringetin-3-*O*-glucoside, and astragalin have been isolated in seed coats of *Nelumbo nucifera* Gaertn plant (Lim 2016). Youn et al. (2010) isolated and analyzed structures of four diverse alkyl 4-hydroxybenzoates from seeds of lotus plant by NMR spectroscopy.

The mass of seed of *Nelumbo nucifera* Gaertn has 3.74% integuments, 3.03% plumule, and 93.23% dicotyledons. *Nelumbo nucifera* Gaertn contains glutathione content of 13 g in its plumule and 164 g in its cotyledon. *Nelumbo nucifera* Gaertn seeds show abundance of asparagin, fats, starch, proteins, and tannins (Toyoda 1966) and a variety of minerals and nutritional elements for example; K-potassium (28.5%), chromium (0.0042%), magnesium (9.20%), Na-sodium (1.00%), Ca-calcium (22.10%), Mg-manganese (0.356%), Co-copper (0.0463%), zinc (0.0840%), and iron (0.1990%), overall ash (4.50%), crude content of carbohydrates (1.93%) and dietary fibre (10.60%), moisture (10.50%), fats (72.17%), and proteins (2.70%) (Indrayan et al. 2005). The major secondary metabolite alkaloids of seeds of *Nelumbo nucifera* Gaertn are pronuciferine, lotusine, nuci-ferine, liensinine, neferine, dauricine, isoliensinine, roemerine, and armepavine (Qian 2002; Wu et al. 2004; Liu et al. 2006; Wang et al. 1991; Furukawa et al. 1965; Tomita et al. 1965; Furukawa 1966), Procyanidin (Ling et al. 2005). The gallic acid, D(–)-3 0-bromo-O-methylarmepavine D–1,2,3,4-tetrahydro-6-methoxy-1-(p-methoxy benzyl)-2-methyl-7-isoquino-linol, carbohydrates, and saponins (Rai et al. 2006) are also present in seeds. The seed polysaccharides isolated and characterized by acid hydrolysis and methylation are four categories of monosaccharide, which are D-mannose, D-galactose, D-glucose, and L-arabinose (Das et al. 1992).

The seed extract prepared in ethanol demonstrates antioxidant action by the use of 2, 2-diphenyl-1picrylhydrazyl (DPPH) assay, wherein free radical scavenging results showed 6.49 mg/ml median inhibition concentration ($IC_{50}$) (Sohn et al. 2003). *Nelumbo nucifera* Gaertn seeds and receptacle possess activities of antioxidation and free-radical scavenging. The hydro-alcoholic seed extract possess antioxidant potential as revealed by in vitro and in vivo models, DPPH assay, and nitric oxide methods (Rai et al. 2006), wherein the complete phenolics amount was reported as 7.61% with strong free radical scavenging capability showing low median inhibition concentration ($IC_{50}$) values (16.12 μg/ml) compared to a standard free radical scavenger, that is, rutin ($IC_{50}$, 18.95 μg/ml) 50 and 84.86 ± 3.56 mg/ml which is reduced than rutin (IC50: 152.17 μg/ml) by the DPPH and nitric oxide assays respectively (Rai et al. 2006).

In vivo study of the hydroalcoholic extract of lotus seeds in Wistar rats at a dosage of 100 mg/kg and 200 mg/kg for 4 days followed by the carbon tetrachloride action lead to considerable dose-dependent enhancement in levels of SOD, catalase, and causes reduction in TBA reactive substances comparative to 100 mg/kg dosage to that of vitamin E at 50 mg/kg (Jiqu et al. 2010). The Swiss Albino mice show no signs and symptoms of acute toxicity up to dosage of 1000 mg/kg body weight (Gutteridge and Halliwell 2000). The macrophage RAW264.7 cell lines showed major free radical scavenging against ROS, and defensive effects against sodium nitroprusside, peroxynitrite induced cytotoxicity, and DNA damage when treated with seed extracts of lotus plant. In comparison to 0.1% butylated hydroxytoluene (BHT), the seed procyanidin and tannin exhibit lipid lipoxygenase inhibition, auto-oxidation, and free radical scavenging ability. Procyanidin at concentration of 62.5 mg/ml showed IC50 value of 21.6 mg/ml and inhibited lipoxygenase action by over 90% (Rai et al. 2006; Ling et al. 2005). Procyanidin and tannin of seed pods have numerous pharmacological properties along with auto-oxidation of lipids, inhibition of lipoxygenase, and free radical scavenging activity paralleled to 0.1% BHT, which inhibits autoxidation of lard (Yen et al. 2006) and remodels age-linked antioxidant deficits in older rats (Ling et al. 2005). Ushimaru et al. (2000) investigated the enzymes with antioxidative potential and their alterations in seedlings of lotus plant, which reacts to deficiency in oxygen levels by the process of germination under aquatic conditions. The enzymatic properties of superoxide dismutase (SOD), dehydro-ascorbate reductase, and glutathione reductase were lesser in lotus seedlings subjected to germination in submerged conditions along with darkness (SD) compared to seedlings subjected to germination in air along with darkness (AD) (Ushimaru et al. 2000).

### 2.2.3 Antioxidant Properties and Phytochemicals Present in Rhizomes of *Nelumbo nucifera* Gaertn

The fresh rhizomes of lotus plant have starch (31.2%) devoid of distinctive flavor or odor (Mukherjee et al. 1995b). The methanolic lotus rhizome extract possesses a betulinic acid which is a steroidal triterpenoid (Mukherjee et al. 1997c). The fresh rhizome has 83.80% water content, 0.11% fat content, 1.56% reducing sugar content, 0.41% sucrose content, 2.70% crude protein content, 9.25% starch content, 0.80% rhizome fibre content, 1.10% ash content, 0.06% Ca-calcium content, thiamine content of 0.22 mg/100 g, riboflavin content of 0.6 mg/100 g, niacin content of 2.10 mg/100 g, ascorbic acid content of 1.5 mg/100 g, asparagine-like amino acid content of 2.00%, and oxalate content of 84.3 mg/100 g (Mukherjee et al. 1996a, b, c).

The antioxidant potential of the methanol rhizome extract and acetone rhizome extract by DPPH assay wherein the maximum DPPH scavenging action was found at 66.73 mg/l in methanol and 133.3 mg/l in acetone (Yang et al. 2007). The methanol rhizome extract revealed an elevated coefficient of antioxidant action contrast to that of ascorbic acid. The lotus rhizome knot showed radical scavenging property which was quantified by spectrophotometer and electron spins resonance (Hu and Skibsted 2002).

### 2.2.4 Antioxidant Properties and Phytochemicals Present in Flowers of *Nelumbo nucifera* Gaertn

Lotus flowers vary in color which became the basis for investigating the phytochemical constitution of the lotus plant. Jung et al. (2003) had obtained seven previously reported flavonoids in androecia of lotus plant together with a few alternatives of the kaempferol. Anthocyanins were also found in flower petals of the lotus plant (Yang et al. 2009). Deng et al. (2013), through HPLC analysis, identified and quantified the flavonoid compounds of 108 cultivars from petals of flowers of lotus plant and found 19 different flavonoid compounds from the class of anthocyanins, flavonols, and flavones. Chen et al. (2013) reported 5 variants of anthocyanins and 20 supplementary flavonoids from petal extracts of 12 varied genotypes wherein the cyanidin 3-*O*-glucoside is one of the reported anthocyanins. The flower stamens and petals comprise approximately indistinguishable array of astragalin flavonoid, rutin flavonoid, and myricetin 3-*O*-galactoside flavonoids (Lim 2016). Further, beta-carotene carotenoids were reported from flowers of 4 *Nelumbo nucifera* Gaertn varieties growing in two different provinces of Thailand (Phonkot et al. 2010).

The flavonoids with potent antioxidant activities recognized in androecia of *Nelumbo nucifera* Gaertn are kaempferol and its seven glycosides: kaempferol 3-O-β-D-glucopyranoside, kaempferol 3-O-β-D-galactopyranoside, kaempferol-3-O-β-D-glucuronopyranoside, kaempferol 3-O-a-L-rhamnopyranosyl-(1–2)-β-D-glucuronopyranoside, kaempferol 7-O-β-D glucopyranoside, kaempferol 3-O-a-L-rhamnopyranosyl-(1-6)-β-D-glucopyranoside, quercetin 3-O-β-D-glucopyranoside, kaempferol 3-O-a-Lrhamnopyranosyl-(1-2)-β-D-glucopyranoside, myricetin 3 0, 5 0-dimethylether 3-O-β-D-glucopyranoside, kaempferol 3-O-β-D-glucuronopyranosyl methyl ester, nelumboroside A and nelumboroside B and two isorhamnetin glycosides known as isorhamnetin 3-O-β-D-glucopyranoside, and isorhamnetin 3-O-a-L-rhamnopyranosyl-(1_6)-β-D-glucopyranoside (Hyun et al. 2006; Jung et al. 2003; Lim et al. 2006). Lim et al. (2006) reported non-flavonoids from stamen extract which includes adenine, arbutin, and β-sitosterol glucopyranoside and myo-inositol. The methanolic stamen and ethyl acetate stamen extracts were used for studying the antioxidant activity of stamen of lotus flower in scavenging genuine peroxynitrites (ONOO-), DPPH, and ROS (Jung et al. 2003).

The kidney homogenates by use of 2v, 7′-dichloro-dihydrofluoresce in diacetate scavenges DPPH free radicals and peroxynitrites ($ONOO^-$) and inhibits ROS generation by DCHF-DA in lotus (Jung et al. 2003). The $IC_{50}$ value (DPPH) of stamen of lotus solutions in methanol of Pathum, Boontharik, Sattabongkot, and Sattabuut were 68.30_6.30, 62.22_ 4.00, 31.60_ 3.40, and 40.90_1.50 _g.mL-1, respectively, whereas of mixed-solvent solutions of Pathum, Boontharik, Sattabongkot, and Sattabuut were 2.21_0.06, 2.23_0.05, 1.29_ 0.02, and 1.83_0.07 mg.mL-1, respectively. The $IC_{50}$ value (DPPH) of Sattabongkot solutions in both solvents was drastically lesser than that of others ($p < 0.05$, at the confidence level of 95%), while the methanol solutions were higher comparative to mixed solvents by 40 folds. The methanol solution retains flavonoids owing to their analogous polarity (Phonkot and Aromdee 2006; Harborne 1998). The mixed-solvent solution retained carotenoids (Phonkot and Aromdee 2006; Horwitz 2000).

### 2.2.5 Antioxidant Properties and Phytochemicals Present in Leaves of *Nelumbo nucifera* Gaertn

*Nelumbo nucifera* Gaertn leaves have potential as a resource of antioxidants. A range of alkaloids N-nornuciferine, (−)-caaverine, (−)-nuciferine, and roemerine were found in the plant leaves (Lim 2016). A total of 15 phytochemical compounds were isolated and identified from leaves of lotus plant, out of which lysicamine, (−)-nuciferine, and (−)-asimilobine were reported as potential natural antioxidants (Liu et al. 2014). The anonaine, liriodenine, and astragalin phytochemicals were also reported in lotus leaves (Mehta et al. 2013). Flavonoids, for example, astragalin, rutin, and quercetin, have been efficaciously isolated from ethanolic leaf extracts of lotus plant (Ohkoshi et al. 2007). Goo et al. (2009) isolated six diverse flavonoid quercetin forms from the methanolic extract of leaves of lotus plant. Chen et al. (2012) mined 13 diverse flavonoids from leaves of *Nelumbo nucifera* Gaertn. Out of which five flavonoids were novel in leaves of lotus plant identified by the use of an improved extraction technique and HPLC investigative method. The above-mentioned reports accentuate the varied amount of bioactive compounds of *Nelumbo nucifera* Gaertn leaves. The overall phenolic acids content of leaf extract of *Nelumbo nucifera* Gaertn plant was decided by Folin–Ciocalteau assay (Zoecklin et al. 1995).

The phenolic content of *Nelumbo nucifera* Gaertn leaves comprises rutin, quercetin, and gallic acid (Lim 2016).

The combined gas/LC/MS has revealed that lotus leaves contain numerous alkaloids. The (+)-1(R)-coclaurine and (−)-1(S)-norcoclaurine benzylisoquinoline alkaloids showed presence in extracts of leaves. The non-phenolic fractions of leaves of *Nelumbo nucifera* Gaertn revealed majority compounds with retention data and mass spectra indistinguishable from anonaine, roemerine, pronuciferine, nuciferine, N-nornuciferine, liriodenine (Mukherjee et al. 1996a, b; 2009), and armepavine and N-methyl-coclaurine phenolic bases as well are present (Kunitomo et al. 1973) Dehydroemetine, remerine, armepavine, roemerine, O-nornuciferine, dehydronuciferine, nuciferine, dehydroanonaine, isoliensinine, N-methylisococlaurine, anonaine, negferine, pronuciferine, liensinine, asimilobine and lirinidine glycoside, nelumboside, flavonoids such as quercetin, quercetin 3-O-aarabinopyranosyl-(1! 2)-_-galactopyranoside, quercetin-3-O-_-D-glucuronide, rutin, (+)-catechin, hyperoside, isoquercitri, and astragalin and leuco-anthocyanidin (leucocyanidin and leucodelphinidin) showed presence in leaves of lotus and petioles (Tomita et al. 1961; Kupchan et al. 1963; Shoji et al. 1987; Nagarajan et al. 1966; Kashiwada et al. 2005; Ohkoshi et al. 2007).

Wu et al. (2003) reported hydrogen peroxide-mediated cytotoxicity in Caco-2 cells to explore the prospective antioxidant capability of the methanol extract from *Nelumbo nucifera* Gaertn leaves. A dose-dependent protective influence against ROS-induced cytotoxicity was detected on treatment of Caco-2 cells with 10 mM hydrogen peroxide and methanol extract of leaves (0.1 mg/ml to 0.3 mg/ml). Lotus extracts revealed concentration-dependent antioxidant potential against hemoglobin-induced linoleic acid peroxidation and Fenton reaction-mediated plasmid DNA oxidation (Wu et al. 2003; Huang et al. 2010a, b). The ethanolic extract of lotus leaves showed in-vivo antioxidant action at 100 mg/kg counter to carbon tetrachloride (CCl4) induced liver toxicity in Sprague–Dawley rats and KM mice comparative to the standard which was a hepatoprotective drug (silymarin) of 100 mg/kg (Wang 2010). The structures of major chemical constituents present in *Nelumbo nucifera* Gaertn are given in Fig. 2.1.

### 2.2.6 Antioxidant Properties of Products Prepared from *Nelumbo nucifera* Gaertn

Scientific investigators have endeavored to incorporate the extracts of different parts of *Nelumbo nucifera* Gaertn like leaves, roots, flowers, and epicarp of seed into different products, together with animal meat, syrup, broth, and liquor and scrutinized their consequence on antioxidant activities.

According to Huang et al. (2011), the root knot and extracts of *Nelumbo nucifera* Gaertn leaves at 3% (w/w) act as antioxidant agent against porcine and bovine minced meat. The lotus root knot was extra effectual against oxidation of lipids during meat storage conditions Extracts of epicarp of lotus seeds equal to 100 μg/mL concentration retard early oxidation of the lipids in homogenates of pork during

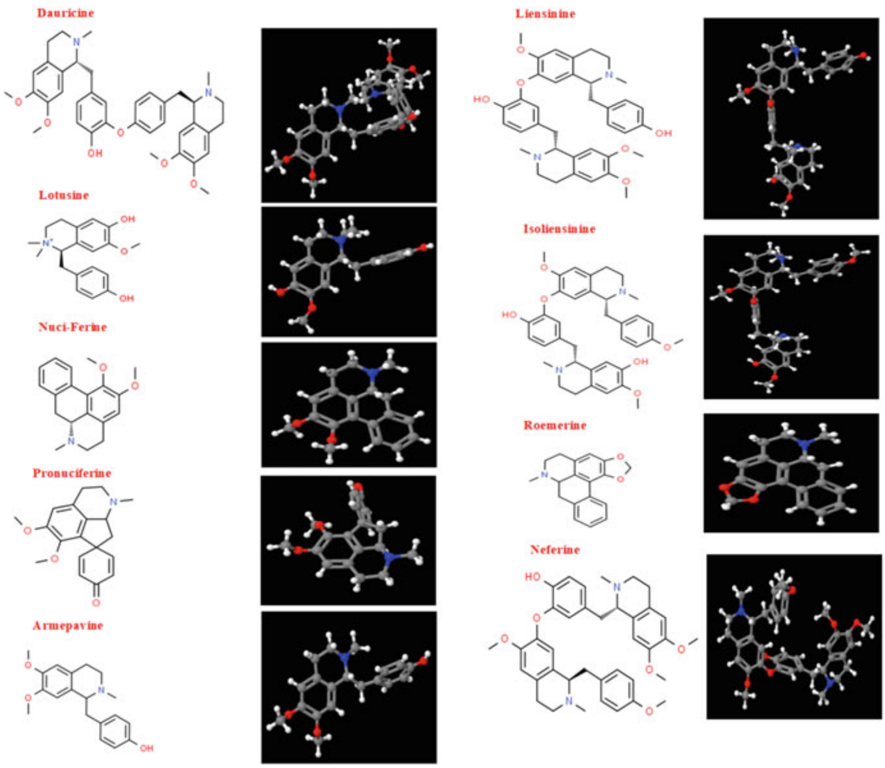


**Fig. 2.1** Chemical structure (2-dimensional and 3-dimensional) of major phytochemicals present in *Nelumbo nucifera* Gaertn

storage conditions (Qi and Zhou 2013). On incorporation of leaf powder of lotus plant during storage, the thiobarbituric acid reactive substances of the refrigerated chicken pastry improved (Choi et al. 2011). Shukla et al. (2016) reported a substantial enhancement in both TPC (521 mg/mL) and TFC (63 mg/mL) was reported throughout fermentation in syrup developed with incorporation of root of lotus plant. This syrup moreover exhibited elevation in antioxidation action, with $IC_{50}$ value of 87.25% in DPPH assay, 99.52% in NO assay, and 44.4% in SOD assay. Additionally, syrup showed anti-tyrosinase action elevation up to 49.8%. Hwang et al. (2015) reported that broth of *Nelumbo nucifera* Gaertn leaves under fermentation for above 180 days displayed antioxidant action analogous to ascorbic acid. Lee et al. (2005) reported that leaves and flowers of *Nelumbo nucifera* Gaertn were practiced to produce customary Korean liquor with antioxidation ability plateau of 80% inhibition at concentration of >25 μg Korean liquor.

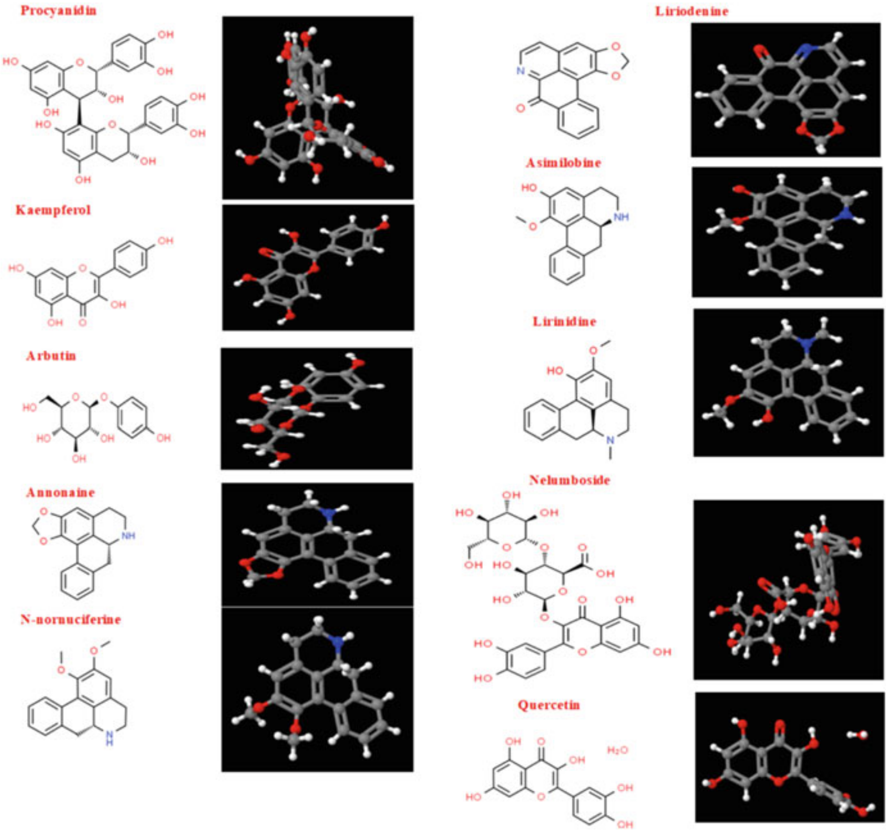


**Fig. 2.1** (continued)

## 2.3 Potential Health Benefits

Plants have been exploited as a resource of drugs by human since antiquity. The aboriginal comprehension of several traditional communities has been devised, documented, and ultimately developed as structured medicinal systems, for example, Ayurveda, Siddha, Unani, and other medicinal systems outside India. *Nelumbo nucifera* Gaertn is fundamentally exploited in Ayurvedic and Unani systems of medicine as cooling, narcotic, astringent, diuretic, and antidiabetic. All the parts of *Nelumbo nucifera* Gaertn are employed therapeutically in contradiction of different human diseases in oriental medicine (Zhou et al. 2009). Ayurveda advocates use of this plant as diuretic and antihelmintic, and for alleviation of strangury, nausea, leprosy, disorders of skin, nervous fatigue (Khare 2004; Sridhar and Bhat 2007), cancer, inflammation of tissue, and as an antidote against toxic substances (Chopra et al. 1956; Liu et al. 2004). Lotus effectively acts as a prospective antioxidant (Rai

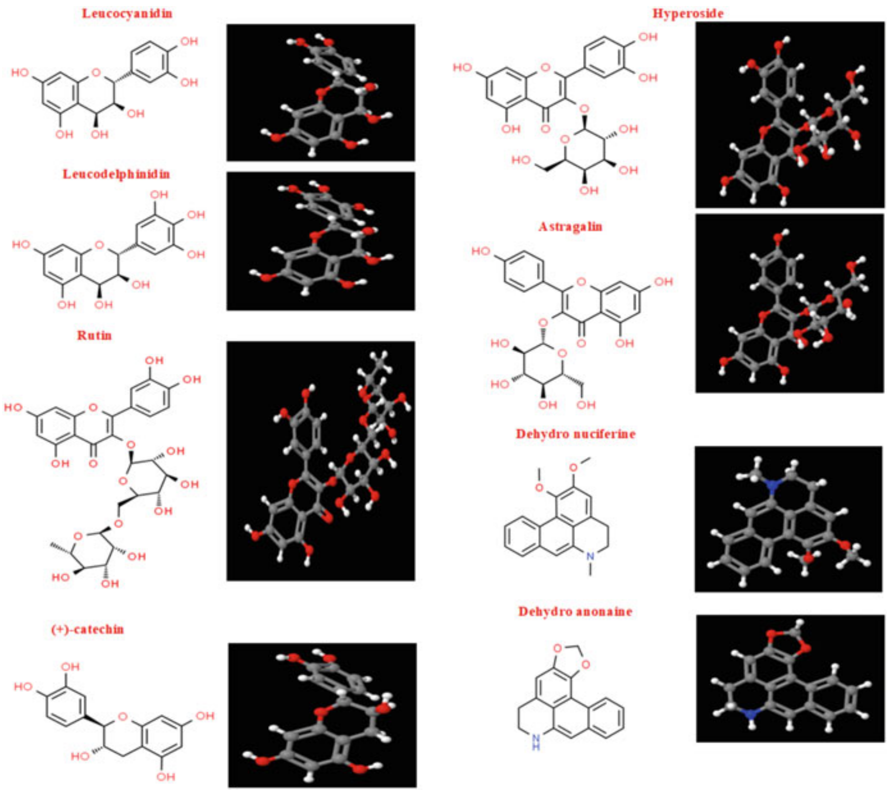


**Fig. 2.1** (continued)

et al. 2006), antipyretic (Deepa et al. 2009), showed antiplatelet (Brindha and Arthi 2010b) and hypoglycemic activity (Mani et al. 2010). Conventionally all parts of *Nelumbo nucifera* Gaertn have therapeutic properties.

**Lotus rhizomes** have nutritive value; they cure dysentery and unremitting dyspepsia; act as diuretic, cholagogue, and demulcent for hemorrhoids; and aid to cure fever (Mukherjee et al. 1997a, c; Kirtikar and Basu 1975; Chatterjee and Pakrashi 1991). The fresh and fleshy rhizome is sweet and aromatic; possess tonic effect; and are consumed for their nutritious value and as a curry known as *Nadru Yakhni* in Kashmir province of Jammu and Kashmir, India. The rhizome when heated in gingelly oil and rubbed on head of a person provides cooling effect to the rubbed area and eyes. It is excellent in cases of dysentery, diarrhea, and dyspepsia. The rhizome paste is applied in ringworm and cutaneous infections (Anon 1966; Nadkarni 1954). The saline lotus rhizome extract possesses bacteriostatic potential (Anonymous 1966). Lotus **leaves** alleviate hyperlipidemia, epistaxis, hematemesis, hematuria, hemoptysis, and metrorrhagia (Onishi et al. 1984). The paste of fresh *Nelumbo nucifera* Gaertn leaves along with sandalwood is useful in the vicinity of burning heat of the skin. The leaf stakes provide cooling effect to forehead in cephalalgia; the milky juice is given in diarrhea (Kirtikar and Basu 1933; Nandkarni 1954) and the tender leaves act as refrigerant in fever. The **flowers** of *Nelumbo nucifera* Gaertn treat fever, diarrheal disorder, cholera, and gastric ulcers (Chopra et al. 1956). *Nelumbo nucifera* Gaertn **seeds** are utilized in folk medications to cure inflammation of tissue, various types of cancers, diuretics, and the skin syndromes (Mukherjee et al. 2010a). Lotus *Nelumbo nucifera* Gaertn **receptacles** are occasionally utilized as a traditional medication for hemostatic purposes (Ling et al. 2005). The Lotus *Nelumbo nucifera* Gaertn **seeds** and **fruits** are exploited as a fitness foodstuff in Asia, and in treating deprived digestion, chronic diarrheal disorder, spermatorrhea, insomnia, enteritis, halitosis, heart palpitations, dermatopathy, menorrhagia, leucorrhoea, leprosy, tissue inflammation, cancer, fever, cardiac problems, antiemetic, antidote, diuretic, and refrigerant (Chopra et al. 1956; Mukherjee et al. 1996a, b; Varshney and Rzóska 1976). The powder of seeds of *Nelumbo nucifera* Gaertn blended with honey is beneficial in treatment of cough (Khare 2004). The seed embryos are employed in traditional Chinese medicine (TCM) for conquering disorders of nervous system, insomnia, towering fevers, and cardiovascular syndromes (Chen et al. 2007).

The numerous pharmacological activities of *Nelumbo nucifera* Gaertn reported include antioxidant (Hu and Skibsted 2002; Hyun et al. 2006), hepatoprotective (Rao et al. 2005), anti-analgesic (Chakravarthi and Gopakumar 2009), immunomodulatory (Mukherjee et al. 2010a), antifertility (Chauhan and Agarwal 2009), psychopharmacological (Mukherjee et al. 1996d), antipyretic (Sinha et al. 2000; Mukherjee et al. 1996e), anticancer (Chopra 1958; Liu et al. 2004; Liu et al. 2006), antiviral (Kuo et al. 2005; Kashiwada et al. 2005), hypoglycemic, antidiarrheal, antifungal, antibacterial, anti-inflammatory, and diuretic activities (Mukherjee et al. 1995a; Mukherjee et al. 1996c; 1997a, b). The other reported pharmacological properties of *Nelumbo nucifera* Gaertn are given in Table 2.2.

## 2.4 Conclusions and Future Pathways

*Nelumbo nucifera* Gaertn possess great momentous advantages in contradiction of the free radicals and ROS species damage. *Nelumbo nucifera* Gaertn is testified to contain an assortment of chemical ingredients which would function as frontrunners in the exploration for novel therapeutic agents. With the accessibility of principal studies, additional scientific investigations on *Nelumbo nucifera* Gaertn should be designed to probe the molecular mechanisms of action by means of specific biological screening models (in vitro) and clinical trials (in vivo) and biosynthetic pathways of isolated phytoprinciples to discover novel leads and the genes responsible from them for modern day drug designing. Furthermore, scientific investigations need to be extended to develop and standardize the procedures for proficient mining and confirmation of active principles of this traditional and medicinal herb *Nelumbo nucifera* Gaertn for the purpose of their utilization in precise herbal formulations for curing various human disorders devoid of side effects

**Table 2.2** Pharmacological properties of different parts of *Nelumbo nucifera* Gaertn

| S. No | Part used | Ethno-medicinal use/Pharmacological activity | Reference |
|---|---|---|---|
| **1** | Leaves | Diarrhea | Nguyen (1999), Ku-Lee et al. (2005) |
| | | High fever | |
| | | Hemorrhoids | |
| | | Leprosy | |
| | | Lipolytic | Ohkoshi et al. (2007) |
| | | Anticancer | Arjun et al. (2012) |
| | | Antiobesity | Ono et al. (2006) |
| | | Cardiovascular activity | Shoji et al. (1987) |
| | | Hypocholesterolemic | Onishi et al. (1984) |
| **2** | Leaf extracts | Analgesic activity | Bera et al. (2011) |
| | | Anthelmintic activities | Lin et al. (2014) |
| | | Antiobesity and hypolipidemic | Du et al. (2010) |
| **3** | Leaves and stem | Hematopoietic | Patel et al. (2012) |
| **4** | Leaf, flower, seed | Cosmetic agent | Kim et al. (2011) |
| **5** | Lotus liquor from leaves & blossoms | Antioxidant, reduces risk of chronic syndromes | Ku-Lee et al. (2005) |
| **6** | Rhizome | Diuretic | Mukherjee et al. (1996a) |
| | | Psycho-pharmacological | Mukherjee et al. (1996b) |
| **7** | Rhizome extract | Antidiabetic | Mukherjee et al. (1997a) |
| | | Antiobesity | Ono et al. (2006) |
| **8** | Flowers, rhizome | Hypoglycemic | Huralikuppi et al. (1991), Lee et al. (2001) |
| | | Antipyretic activity | Mukherjee et al. (1996c), Sinha et al. (2000) |
| | | Antidiabetic | Rakesh et al. (2011) |
| **9** | Leaves, flower, rhizome | Antioxidant | Wu et al. (2003), Jung et al. (2003), Hyun et al. (2006) |
| **10** | Flower | Antimicrobial activity | Brindha and Arthi (2010a) |
| | | Anti-platelet | Brindha and Arthi (2010b) |
| | | Aldose reductase inhibitory | Lim et al. (2006) |
| | | Vasodilating effects, antihypertensive, and antiarrhythmic abilities | Ku-Lee et al. (2005) |
| | | Antioxidant | Krishnamoorthy et al. (2009) |
| | | Antibacterial, antioxidant | Venkatesh and Dorai (2011) |
| | | Antioxidant, free radical scavenging | Durairaj and Dorai (2014) |

(continued)

**Table 2.2** (continued)

| S. No | Part used | Ethno-medicinal use/Pharmacological activity | Reference |
|---|---|---|---|
| **11** | Beverages of flower | Hypertension, cancer, feebleness, body heat balance | Saengkhae et al. (2008) |
| **12** | Androecia | Consolidation of kidney function, disorders of male sexuality, leucorrhea of females | Nguyen (1999) |
| | | Aphrodisiac | Vahitha Bi et al. (2012) |
| **15** | Flower receptacles | To stop bleeding and to eliminate stagnated blood | Ku-Lee et al. (2005) |
| **16** | Seed | Antiproliferative | Yu and Hu (1997) |
| | | Antifibrosis | Xiao et al. (2005) |
| | | Antifertility | Mutreja et al. (2008) |
| | | Antidepressant, anti-inflammation | Bi et al. (2006) |
| | | Anti-ischemic/cardiovascular symptoms | Kim et al. (2006) |
| **17** | Ripe seeds | Astringent action, chronic diarrhea | Nguyen (1999) |
| | | Spleen tonic | Follett and Douglas (2003) |
| **18** | Seed powder | Cough | Khare (2004) |
| **19** | Seed extracts | Hepatoprotective, free radical scavenging | Ono et al. (2006) |
| | | Antiobesity, Antihypolipidemic | You et al. (2014) |
| **20** | Plumule of ripe seed | Nervous maladies, insomnia, elevated fevers with restlessness and hypertension | Nguyen (1999) |
| **21** | Seed, rhizome | Anti-inflammatory | Mukherjee et al. (1997), Lin et al. (2006) |
| | | Immunomodulatory | Mukherjee et al. (2010b) |
| **22** | Seed, leaves | Hepatoprotective | Huang et al. (2010b) |
| | | Antiviral | Kashiwada et al. (2005), Kuo et al. (2005) |
| **23** | Plant extract | Anti-hyperlipidemic activity | Subasini et al. (2014) |

Source: Modified from Sheikh SA (2014): Ethno-medicinal uses and pharmacological activities of lotus (*Nelumbo nucifera*). *Journal of Medicinal Plants Studies* 2(6): 42–46

and should be advanced for human clinical trials. Finally, there is urgent need for conservation of lotus plant as its habitat is getting disturbed, threatened, and polluted because of various anthropogenic activities.

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# Beetroot

# 3

Deepu Pandita, Anu Pandita, Ramachandra Reddy Pamuru, and Gulzar Ahmad Nayik

**Abstract**

*Beta vulgaris* subsp. *vulgaris* L is a root vegetable from Chenopodiaceae family. *Beta vulgaris* L. ssp. *vulgaris* positions among the 10 most potent antioxidant vegetables due to presence of betalains, phenolic acids, saponins, alkaloids, steroids/triterpenes, catechins, and flavonoids. The antioxidant activity of beetroot acts as defense against the oxidative damage caused by ROS or free radicals in the cell which may alter cell metabolism, cause DNA damage, and structural and functional impairment of lipids and proteins. Beetroot makes an outstanding dietary supplement being abundant not only in nutrients, minerals and vitamins, vitamin B complex, and folic acid but also has plethora of unique bioactive compounds bestowed with a number of medicinal and therapeutic properties. Several parts of beetroot possess medicinal properties as analgesic, hepatoprotective, antioxidant, antimicrobial, anti-inflammatory, antimigraine, antihypertension, antiviral, antihyperglycemic, anti-progestogenic, antiallergic, antithrombotic, anti-tumorigenic, and prevents neurodegeneration and hepatic damage.

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**Keywords**

Beetroot · Antioxidant activity · Reactive oxygen species · Betalains · Saponins · Flavonoids

## 3.1 Introduction

**Botanical Name**
*Beta vulgaris* Linn. ssp. *vulgaris*

**Common/Vernacular Names**
**Hindi:** Chukandar
**English:** Beetroot, Red Garden Beet, Table Beet, Harvard Beet, Blood Turnip, Garden Beet, Red Beet, Golden Beet, Dinner Beet, Spinach Beet

Beta genus belongs to a family of the flowering plants known as Amaranthaceae or Chenopodiaceae. Most plant classifications, notably the Cronquist system, placed beetroot species in Chenopodiaceae, while the APG (1998) and APG II system (2003), in lieu of evidence from molecular phylogenies, placed beetroot in the family Amaranthaceae. Some classification systems consider that the beetroot belongs to subfamily of Chenopodiaceae and family of Amaranthaceae. The beet was cultivated as a leafy pot plant in ancient periods (Ford-Lloyd et al. 1975; De Bock 1986). *Beta vulgaris* L. with chromosome number $2n = 2x = 18$ can be divided into three subspecies which are (1) *Beta vulgaris* ssp. *adanesis*, (2) *Beta vulgaris* ssp. *maritime*, (3) *Beta vulgaris* ssp. *vulgaris*, including the cultivated varieties (Lange et al. 1999). The beetroot originated from the wild/sea beet known as *Beta maritime* botanically in Eurasia. Lange et al. (1999) was of the opinion that *Beta vulgaris* ssp. *vulgaris* can be divided into four additional groups:

(a) **Leaf Beet Group**, a cultivar which has edible leaves and leaf petioles. The roots are slightly with enhanced diameter than other beet groups.
(b) **Sugar Beet Group**, a cultivar which is white in color, and cultivated in the USA and Europe for the production of sugar since the XVI century.
(c) **Fodder Beet Group**, a cultivar used as fodder crop.
(d) **Garden Beet Group**, the solitary cultivar which has an edible tuberous root and is consumed as a vegetable.

*Beta vulgaris* L. ssp. *vulgaris* has a number of varieties whose color vary from shades of yellow to red, while the most cultivated and widely used is the deep red–colored beets (Ibraheem et al. 2016). The beetroot is the taproot of plant. The betacyanin and betaxanthin (betalains) are heterocyclic and water-soluble nitrogen pigments which provide red-purple color to beetroot tubers and act as antioxidant agents (Ravichandran et al. 2013; Volp et al. 2009). The content of betacyanin and betaxanthin pigments present in cell vacuoles of beetroot varies toward a larger or reduced content in beetroot varieties like Burpee's golden and Albina Vereduna, which are not typical deep red colored (Hamilton 2005). The red pigment betacyanin of beetroot leads to red excretory products in individuals and the condition is called beeturia (Eastwood and Nyhlin 1995). The betalains can be divided into two subclasses on the basis of their chemical structure which are 20 types of betaxanthins (e.g., vulgaxanthin I and II and indicaxanthin), accountable to orange-yellow colorations and 50 types of betacyanins (e.g., prebetanin, betanin, neobetanin, isobetanine, etc.), responsible for red-violet colorations (Ravichandran et al. 2013; Volp et al. 2009). *Beta vulgaris* L. ssp. *vulgaris* contains about 75–95% betacyanin content and 5–25% betaxanthine content (Volp et al. 2009; Delgado-Vargas et al. 2000). Content of betacyanin and betaxanthine exists in greater concentrations on the covering of beetroot and progressively declines toward the interior of the beet (pulp and crown) (Stintzing and Carle 2004; Kujala et al. 2000; Delgado-Vargas et al. 2000). *Beta vulgaris* L. ssp. *vulgaris* is the basis of marketable betalains (concentrate and/or powder form) for their usage as natural dye or red food colorants to dairy products, tomato paste, gelatins, confectionery, sauces, sweets and desserts, dry mixes, jams, and chicken-derivative food stuffs (Delgado-Vargas et al. 2000; Oyen 2004). Beetroots contain phenolic compounds with antioxidant potential (Wootton-Beard et al. 2011). The flavonoids, phenolic amides, and ferulic acids in peels of *Beta vulgaris* L. ssp. *vulgaris* confer antioxidant potential to it (Kujala et al. 2000, 2002). Some 11 oleanoic acid–based saponins found in beets (Mroczek et al. 2012) cause hypoglycemic effects in humans (Murakami et al. 1999). Beetroot with high nutritional value is one among the 10 utmost potent plants with antioxidant potential, which stabilize the free radicals produced by the cells and thus avert the oxidative stress in biological molecules (Vulic et al. 2012; Vinson et al. 1998; Pedreño and Escribano 2001). It is known for its richness of antioxidants and the bioactive compounds in the form of betalains, carotenoids, phenolic compounds, and goodness of other phytochemicals and nutrients (Stratus et al. 2012; Gamage et al. 2016), which improve well-being of humans, function of body organs, prolongs longevity, and provides defense against various disorders and degenerative syndromes (Azeredo 2009) and shows therapeutic properties as anti-inflammatory, anticancerous, antiproliferative, and hepatoprotective effects (Ibraheem et al. 2016; Neagu and Barbu 2014; Ahmad et al. 2013; Boivin et al. 2009; Georgiev et al. 2010; Kapadia et al. 2003; Winkler et al. 2005). Beetroot is main dietary sources of nitrate. NO regulates vascular tonus and relaxes smooth muscle cells (Bryan and Ivy 2015); destructs parasites, microorganisms, and tumor cells (James 1995); acts as neurotransmitter (Dawson 1994); maintains vascular homeostasis; and controls proliferation and growth of smooth muscles (Machha and Schechter 2011).

Diverse beetroot formulations, such as beetroot juice (Coles and Clifton 2012), beetroot powder (Kaimainen et al. 2015; Vasconcellos et al. 2016), food products made from beetroot flour like barfi and kanjhi (Dhawan and Sharma 2019), beetroot chips (Vasconcellos et al. 2016), and beetroot gel (da Silva et al. 2016) have been developed. In 1975 Apollo-Soyuz Test Project, a soup squeezed from tubers of beets known as Borscht was offered by the cosmonauts of Soyuz 19 to astronauts of

Apollo 18 (www.nasa.gov). Beetroot salad helps in the growth of fetus during pregnancy (Chawla et al. 2016). Beetroots act as remedy against poisoning by cyanide in African culture (Kumar 2015a). Dr. Manto Tshabalala-Msimang, the then health minister in Government of South Africa was named “Dr Beetroot” for promotion of beets above antiretroviral AIDS medicines (Blandy 2006).

In this context, this chapter discusses the origin and history, distribution, production, nutritional composition, phytochemicals and their antioxidant activities, therapeutic values, and the consequences of *Beta vulgaris* L. ssp. *vulgaris* ingestion on human health.

### 3.1.1 Origin and History of Beetroot

According to Campbell (1979), beet species have originated from *Beta maritime*, commonly known as the wild beet or sea beet, which was indigenous to the Southern Europe, alongside the shorelines of Mediterranean. The species of beetroot, that is, *Beta vulgaris* L. ssp. *vulgaris* had origin from provinces of Europe and North Africa, where these are subjected to cultivation in low to cold temperatures of 10–20 °C (Tullio et al. 2013). The ancient archeological remnants from Neolithic location of Aartswoud in north Netherlands and Saqqara pyramid at Thebes, Egypt, dating back to Third Dynasty (2650–2575 BC), provide evidence of beetroot consumption from prime val epochs (Murthy and Manchali 2013). Primordial Greeks cultivated and consumed beetroot leaves (300 BC), worshipped the Greek Sun God, named Apollo in His temple at Delphi by offering beetroots on silver platter and considered beetroot equivalent to its weight in silver (Leyel 2007). Ancient folk magic suggests that if a man and woman eat same beet, they fall in love. In mythology, Aphrodite is believed to have consumed beetroot for the preservation of her beauty (Masley 2018). “The Acharnians” and “Peace” were dual comedies transcribed by Aristophanes, and later on their performance in Athens in 420 BC records the first reference of beetroot (Nottingham 2004). An ancient Assyrian manuscript (800 BC) mentions beetroot (named as *silga*) cultivation in Hanging Gardens of Babylon, Mesopotamia (von Lippmann 1925; Deerr 1950). In 812 BC (Capitulare of Villis), the “Regulation Concerning Landed Property,” recorded *B. vulgaris* plant to be mainly cultivated in estates of Imperial State. In mid-era, *B. vulgaris* ssp. *vulgaris* as Roman beet was under cultivation because of plant roots in the Spanish, French, and Italian monastery gardens (Nottingham 2004). During this era, beetroot was used for medicinal value against disorders of digestion and blood. Bartolomeo Platina suggested that beetroot abolishes the consequences of “garlic breath” (Kale and Masalkar 1993). Zohary and Hopf (2000) believed that the most aboriginal acknowledged written record of the beet dates back to eighth century B.C.E. Mesopotamia and that the “Roman and Jewish literary sources signpost the presence of earliest leafy forms (chard) of domesticated beet in the Mediterranean basin in 1$^{st}$ century B.C.E. and possibly beetroot cultivars” as well. Talmud book of fourth and fifth century recommends beetroot usage for longevity. Romans considered roots as laxative or antidote against fever. Apicius in his book *The Art of Cooking* suggested its use as food with many recipes. Victorians practiced beetroot for coloring the diet and as sweeting agent of desserts. In the late fifteenth century, beets were cultivated for their leaves and roots all through Europe (Nottingham 2004; Deerr 1949/50). The middle of nineteenth century witnessed coloring of wine with juice of beetroot (Mohandas 1987). Modern-day beetroot appeared in the sixteenth and seventeenth century Europe and became widespread in Central and Eastern Europe in next few centuries. A range of beet forms have been cultivated all through the years. The first beet varieties were present in the Palatinate around 1700 (Knapp 1958), whereas in 1778, the cultivation of “pastoral” beet variety “Dick Wurzel,” was proclaimed for the first time in France by Philippe de Vilmorin. The mangel-wurzel beet variety originated from the yellow beet in the late 1700. Prussians in 1700 did breeding selections in varieties of “Blanche de Silésie,” which led to the origin of a variety with high sugar content known as sugar beets (Ashworth 2002; Bougy 1936; Fischer 1989) and fodder sugar beet “Géante Blanche.” English and German foundations showed that the *B. vulgaris* ssp. *vulgaris* were frequently domesticated in Medieval Europe (Kumar 2015a). The leaves of beetroot were considered edible while the roots were used for medicinal purposes only. Romans not only used beet therapeutically, but were pioneers in cultivation of beet for root as well. Romans named beet as beta (Norton and Espito 1994).

The earliest Greeks subjected beets to cultivation for their leaves, both for culinary and medicinal purposes, and named beets as *teutlon* or *teutlion*, since the foliage (Nottingham 2004) or the fangy root systems of initial beets resembled squid tentacles (Ford-Lloyd et al. 1975). Hippocrates and Theophrastus mentioned the beet varieties with fleshy-textured roots as medicinal plants (de Vilmorin 1923). Hippocrates suggested usage of beetroot leaves for fixing and dressing wounds. Theophrastus described the beet as a garden plant similar to radish and differentiated between the dark-colored beet forms and pale-colored beet forms. Andreas Marggraf (1747) isolated the sucrose in the *B. vulgaris* ssp. *vulgaris* after which Franz Karl Achard constructed a sugar beet processing industrial unit in Silesia, under the patronage of King of Prussia (Frederick William III) in the mid-1800 (Hanelt et al. 2001). Genus Beta predominantly exists in Asian and European continents (Campbell 1979). The details of historical events of Beetroot are given in Fig. 3.1.

### 3.1.2 Distribution and Production of Beetroot (India, World)

*Beta vulgaris* L. ssp. *vulgaris* is ubiquitous. The beet is aboriginal of Mediterranean Europe and North Africa. Afterwards beetroot distributed throughout Europe and western parts of India, and established a secondary diversity center in Near East. Beetroot is an important vegetable crop at global level with an irreplaceable niche in the Middle East, Europe, North America, and portions of Asia plus India. The European countries are pronounced consumers of beetroot while the central producers are England and France. In Spain, beetroot is cultivated on 564 ha, which is 0.14% of the total area under cultivation of vegetables. The majority of the beetroot culture (97%) is generally done in the open on irrigated land and only

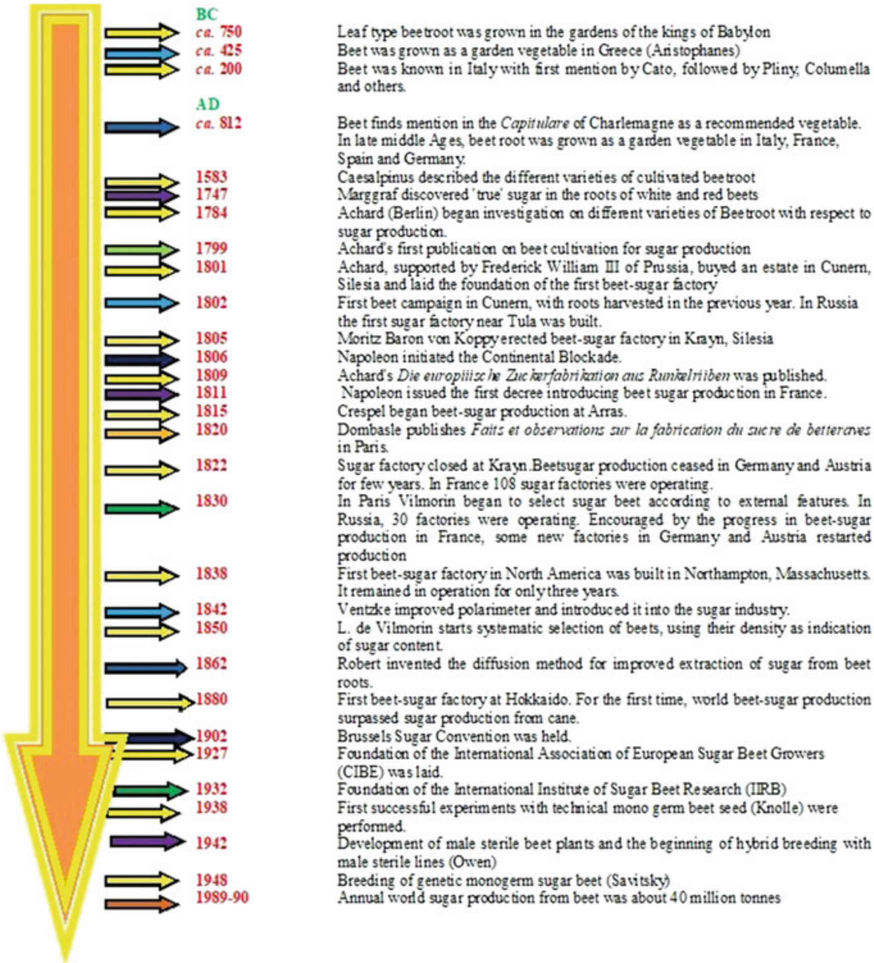


**Fig. 3.1 Historical timetable of beetroot. (Source:** Cooke DA, Scott RK (1993) The Sugar Beet Crop, Published by Chapman & Hall, 2–6 Boundary Row, London)

0.03% is cultivated on dry land. The Spanish production of beetroot primarily envisioned for fresh consumption (82%) was 12,458 tons in year 1995. The average yields were 22.5 tons/ha in hydrated land and 10.1 tons/ha in dehydrated land.

Indian area under *Beta vulgaris* L. ssp. *vulgaris* cultivation is around 5000 ha, which produces 90,000 tons annually (Anonymous 2001). The Indian states under beetroot cultivation are mainly Himachal Pradesh, Haryana, Maharashtra, West Bengal, and Uttar Pradesh. Beetroot propagates abundantly all throughout India, extending from the peaks of south to frosty zones of north. According to UN Comtrade (2012) figures, India ranks at 45th position in the export of beetroot and accounts for below 0.08% of international trade signifying that the maximum production of beetroot is utilized in domestic consumption. Annually 40–50 tons of beetroot seed are imported and retailed by private establishments in India. Being fundamentally a cold climate crop, beetroot propagates finest in the plains of India in the winter with little warm weather. Superior quality roots, which contain abundant sugar content with extreme red color, are cultivated in cold climates where temperature ranges from 18.3 °C to 21.1 °C. At below 100 °C temperature, beetroot plant undergoes wilting earlier to achieving root size of marketable value (Sadhu 1986). In the Indian state of Tamil Nadu during session 2016–2017, the beetroot cultivable area was 1542 hectares with production of 40,818 tons and productivity of 26.47 tons/ha. The chief beetroot propagating districts in the state of Tamil Nadu are Tirupur (33.42%), Theni (17.47%), the Nilgiris (14.60%), Dindigul (13.98%), Coimbatore (11.56%), Krishnagiri (6.45%) and Erode (1.16%).

### 3.1.3 Botanical Description of *Beta vulgaris* L. ssp. *vulgaris*

**Scientific classification**

| | |
|---|---|
| **Kingdom:** | Plantae |
| **Subkingdom:** | Tracheobionta |
| **Super division:** | Spermatophyta |
| **Division:** | Magnoliophyta |
| **Class:** | Magnoliopsida |
| **Subclass:** | Caryophyllidae |
| **Order:** | Caryophyllales |
| **Family:** | Chenopodiaceae |
| **Genus:** | Beta |
| **Species:** | vulgaris |
| **Subspecies:** | *Beta vulgaris* L. subsp. *vulgaris* |
| **Cultivar Group:** | “Conditiva” |

### 3.1.4 Different Varietal Groups of *Beta vulgaris* L. ssp. *vulgaris*

Goldman and Navazio (2008) have classified *Beta vulgaris* L. ssp. *vulgaris* varieties as under with slightly different morphologies:

**Detroit Dark Red**
This variety has been developed from Early Blood Turnip by Mr. Reeves of Canada. Roots of this variety are smooth and perfectly round with deep red skin. The foliage of Detroit Dark Red variety is dark green in color. The yield is high and has duration of 80–100 days.

**Early Wonder/Detroit Early Dark Red/Detroit Blood/Early Detroit Dark Red**
This variety was named by FH Woodruff and Sons; and SD Woodruff and Sons in 1911 and was obtained from Crosby Egyptian. The Roots of this variety are flat globular with dark red peel and pulp with light red zoning. The foliage is robust. This variety matures in 80–100 days.

**Crosby Egyptian**
It originated and developed from the Flat Egyptian variety by Crosby of Massachusetts. Roots are flat globe with increased depth and less rough root exterior. The variety is rounder and smoother than Flat Egyptian variety.

**Flat Egyptian**
This variety was brought into USA by the Ernst Benary Company (1868). This variety has small-sized, flat roots which are suitable for canning. Roots have dark purplish-red flesh with white zoning in warm weather. This variety has small foliage and matures in 55–60 days.

**Light Red Crosby**
This variety was initially defined by Ferry and Co (1904). It is vermillion or light-red in color. The root and peel color are lighter than the original Crosby.

**Ohio Canner**
This variety was developed at the Ohio Agricultural Experiment Station, USA (1932). The skin and flesh of root and foliage has color analogous to Detroit Dark Red, but with lesser quantity of differential coloring of zoning.

**Long Dark Blood**
This variety is possibly the primogenital beetroot in the US introduced from France. The roots are long and cylindrical.

**Ruby Queen**
This variety was introduced by private seed companies in India. The seed of this variety was imported from Italy. Roots are round in shape and red in color with less white zoning.

### 3.1.5 Nutritive Value of *Beta vulgaris* L. ssp. *vulgaris*

*Beta vulgaris* L. ssp. *Vulgaris* is an excellent cradle of higher nutrients among which stand out the carbohydrates, sucrose, proteins, minerals, vitamins (ascorbic acid, B-complex, and vitamin C), fiber, minerals, antioxidants, betalains, and phenolic compounds (Lundberg et al. 2008; van Velzen et al. 2008; Aykroyd 1963). The data of United States Department of Agriculture (USDA) for macronutrient values in 100 mg of raw beetroot and raw beetroot greens is presented in Table 3.1.

**Table 3.1** Nutritive value of beetroot and beetroot greens, raw per 100 mg

| Nutrients | Beetroot {Amount} | Beet Greens {Amount} |
|---|---|---|
| Water | 87.58 gm | 91.02 gm |
| Energy | 43 kcal | 22 kcal |
| Ash | 1.08 gm | 2.33 gm |
| Betaine | 128.7 mg | 0.4 mg |
| Calcium, Ca | 16 mg | 117 mg |
| Carbohydrate, by difference | 9.56 gm | 4.33 gm |
| Carotene, alpha | 0 µg | 3 µg |
| Carotene, beta | 20 µg | 3794 µg |
| Choline, total | 6 mg | 15 mg |
| Copper, Cu | 0.075 mg | 0.191 mg |
| Cryptoxanthin, beta | 0 µg | 0 µg |
| Dietary fiber | 2.8 gm | 3.7 gm |
| Energy | 180 kJ | 92 kJ |
| Folate, DFE | 109 µg | 15 µg |
| Folate, food | 109 µg | 15 µg |
| Folate, total | 109 µg | 15 µg |
| Folic acid | 0 µg | 0 µg |
| Iron, Fe | 0.8 mg | 2.57 mg |
| Magnesium, Mg | 23 mg | 70 mg |
| Manganese, Mn | 0.329 mg | 0.391 mg |
| Niacin | 0.334 mg | 0.4 mg |
| Pantothenic acid | 0.155 mg | 0.25 mg |
| Phosphorus, P | 40 mg | 41 mg |
| Potassium, K | 325 mg | 762 mg |
| Protein | 1.61 gm | 2.2 gm |
| Retinol | 0 µg | 0 µg |
| Riboflavin | 0.04 mg | 0.22 mg |
| Selenium, Se | 0.7 mg | 0.9 mg |
| Sodium, Na | 78 mg | 226 mg |
| Sugars, total including NLEA | 6.76 gm | 0.5 gm |
| Thiamin | 0.031 mg | 0.1 mg |
| Total lipid (fat) | 0.17 gm | 0.13 gm |
| Vitamin A, IU | 33 IU | 6326 IU |
| Vitamin A, RAE | 2 µg | 316 µg |
| Vitamin B-12 | 0 µg | 0 µg |
| Vitamin B-12, added | 0 µg | 0 µg |
| Vitamin B-6 | 0.067 mg | 0.106 mg |
| Vitamin C, total ascorbic acid | 4.9 mg | 30 mg |
| Zinc, Zn | 0.35 mg | 0.38 mg |
| Lutein + zeaxanthin | 0 µg | 1503 µg |
| Lycopene | 0 µg | 0 µg |
| Vitamin D (D2 + D3) | 0 international units | 0 international units |
| Vitamin D (D2 + D3) | 0 µg | 0 µg |

(continued)

**Table 3.1** (continued)

| Nutrients | Beetroot {Amount} | Beet Greens {Amount} |
|---|---|---|
| Vitamin E (alpha-tocopherol) | 0.04 mg | 1.5 mg |
| Vitamin E, added | 0 mg | 0 mg |
| Vitamin K (phylloquinone) | 0.2 μg | 400 μg |
| Fatty acids, total saturated | 0.027 gm | 0.02 gm |
| 4:0 | 0 gm | 0 gm |
| 6:0 | 0 gm | 0 gm |
| 8:0 | 0 gm | 0 gm |
| 10:0 | 0 gm | 0 gm |
| 12:0 | 0 gm | 0 gm |
| 14:0 | 0 gm | 0 gm |
| 16:0 | 0.026 gm | 0.02 gm |
| 18:0 | 0.001 gm | 0 gm |
| Fatty acids, total monounsaturated | 0.032 gm | 0.026 gm |
| 16:1 | 0 gm | 0 gm |
| 18:1 | 0.032 gm | 0.026 gm |
| 20:1 | 0 gm | 0 gm |
| 22:1 | 0 gm | 0 gm |
| Fatty acids, total polyunsaturated | 0.06 gm | 0.046 gm |
| 18:2 | 0.055 gm | 0.041 gm |
| 18:3 | 0.005 gm | 0.004 gm |
| 18:4 | 0 gm | 0 gm |
| 20:4 | 0 gm | 0 gm |
| 20:5 n-3 (EPA) | 0 gm | 0 gm |
| 22:5 n-3 (DPA) | 0 gm | 0 gm |
| 22:6 n-3 (DHA) | 0 gm | 0 gm |
| Fatty acids, total trans | 0 gm | 0 gm |
| Cholesterol | 0 mg | 0 gm |
| Tryptophan | 0.019 gm | 0.035 gm |
| Alanine | 0.06 gm | 0.081 gm |
| Alcohol, ethyl | 0 gm | 0 gm |
| Arginine | 0.042 gm | 0.063 gm |
| Aspartic acid | 0.116 gm | 0.129 gm |
| Caffeine | 0 mg | 0 mg |
| Cystine | 0.019 gm | 0.021 gm |
| Glutamic acid | 0.428 gm | 0.267 gm |
| Glycine | 0.031 gm | 0.081 gm |
| Histidine | 0.021 gm | 0.034 gm |
| Isoleucine | 0.048 gm | 0.046 gm |
| Leucine | 0.068 gm | 0.098 gm |
| Lysine | 0.058 gm | 0.064 gm |
| Methionine | 0.018 gm | 0.018 gm |
| Phenylalanine | 0.046 gm | 0.058 gm |
| Proline | 0.042 gm | 0.052 gm |

(continued)

**Table 3.1** (continued)

| Nutrients | Beetroot {Amount} | Beet Greens {Amount} |
|---|---|---|
| Serine | 0.059 gm | 0.07 gm |
| Theobromine | 0 mg | 0 mg |
| Threonine | 0.047 gm | 0.065 gm |
| Tyrosine | 0.038 gm | 0.052 gm |
| Valine | 0.056 gm | 0.065 gm |

**Source:** United States Department of Agriculture Agricultural Research Service (2019) Food Data Central: Food and Nutrient Database for Dietary Studies with Standard Reference Legacy Release in April 2019. Retrieved 10-03-2020. www. *fdc.nal.usda.gov*

## 3.2 Antioxidant Properties and Phytochemistry of Beetroot

### 3.2.1 Antioxidant Properties

Protection of cellular contents from oxidative damage by antioxidant defense is a common mechanism takes up in the cellular activity. Oxidative damage leads to release of reactive oxygen species (ROS or free radicals) in the cell metabolism. At low levels, ROS helps to protect the cellular system with respect to muscle contraction, cell proliferation, gene expression, and apoptosis. Excess amounts of ROS produced by exogenous or endogenous stimuli can damage the tissue or cells and cause imbalance in the redox homeostasis, which leads to DNA damage and structural and functional impairment of lipids and proteins (Kohen and Nyska 2002; Reuter et al. 2010). In common, the oxidative stress generated by elevated ROS levels sometimes can be reverted back and temporarily weaken the cellular antioxidant defense system. However, the ROS elevation damages the oxidative defense permanently in the chronic diseases like cancer and causes long-term cellular damage (Lobo et al. 2010).

The antioxidant property of beetroot is mainly due to the presence of phytochemicals such as phenolic acids, catechins, and flavonoids. These phytochemicals are found to act against hypertensive, hyperglycemic, inflammatory, and hepatic damages (Vali et al. 2007; Ninfali and Angelino 2013; Singh et al. 2011; Jain et al. 2011). Beetroot is a potential food for strong antioxidant activity among several vegetables tested (Kapadia et al. 2011). Rutin, caffeic acid, and epicatechin are the richest bioactive phenolics or beetroot, holding excellent oxidative defense (Georgiev et al. 2010; Tesoriere et al. 2004). Betalains are nontoxic, nitrogenous pigments, soluble in water, and found richly in beetroot. Naturally, they form as betaxanthins (yellow) and betacyanins (red) in beetroot and are highly used in food industry as additives (Reddy et al. 2005; Oksuz et al. 2015). Beetroot phenolic compounds hold the function of free radical oxidation termination, a potential antioxidant property, which protects from various disorders and straightens the altered biological functions (Lee et al. 2007). Antioxidant activity and potential health benefits of beetroot supplementation are well reviewed by Tom et al. (2015).

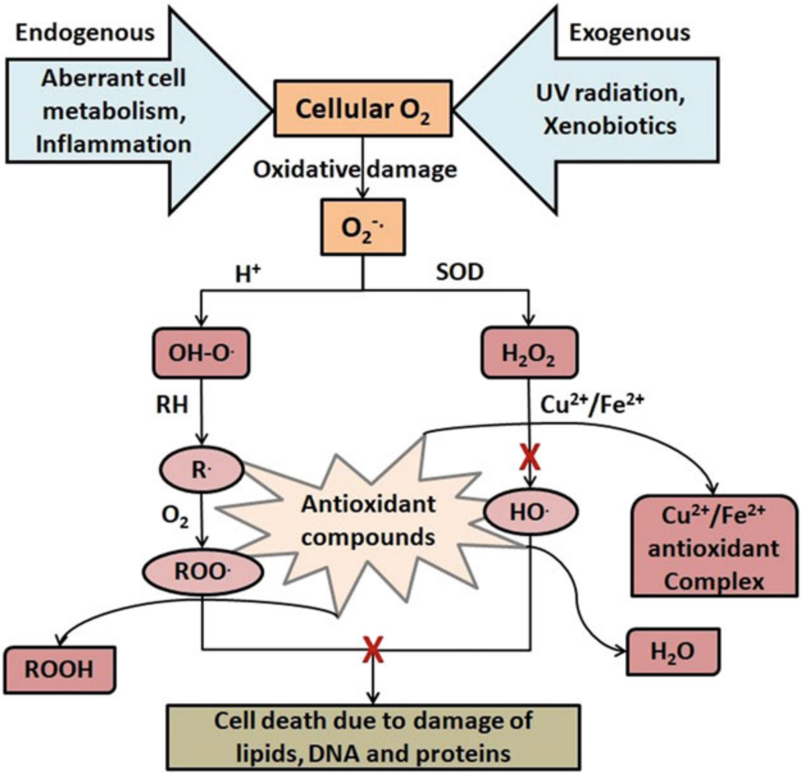


**Fig. 3.2** Mechanism of ROS scavenging system and action of beetroot antioxidant compounds (*$O_2$* Oxygen, *$H^+$* hydrogen ion, *$O_2^{-}\bullet$* superoxide anion, *SOD* superoxide dismutase (converts superoxide anions into hydrogen peroxide which are detoxified by catalase/glutathione peroxidase), *OH-O* perhydroxyl radical, *$H_2O_2$* hydrogen peroxide, *RH* lipid, *R* lipid alkyl radical, *ROO* lipid peroxyl radical, *ROOH* lipid hydroperoxide, *HO* hydroxyl radical, *$Cu^{2+}/Fe^{2+}$* copper/ferrous ions)

The general mechanistic action of antioxidant compounds on reactive oxygen species scavenging system is presented in Fig. 3.2.

## 3.2.2 Juices

The juice of beetroots consists of antioxidants which reduce the inflammation and blood pressure. Beet juices are advised to athletes to have better performance in sports and games. The nutritional value of beetroot juice placed it as a vegetable of health. The studies focused on better health benefits of beetroot components as juice instead of raw or cooked forms. The nitrate content of beetroot is converted into nitric oxide in the digestive system and is believed to lower the blood pressure by dilating the blood vessels thereby increases the blood flow. It is proved experimentally by supplementing the nitrate-rich and non-nitrated beetroot juice to two individual groups. They found that nitrated juice consumed group has lowered 5.2 ml of mercury in the blood pressure machine after 30 min and is continued until 24 h when compared to non-nitrated group. However, the reports are not sufficient to explain the role of beetroot juice in the lowering of high blood pressure in patients (Catherine et al. 2015).

The components of beet juice supplements the betalains and betacyanins (betanin and isobetanin), which protects the individual against damage of DNA, protein, and lipid (Kujawska et al. 2009; Winkler et al. 2005). It is possible through the activity of oxidative stress release, where the beetroot phytochemicals inhibited the formation of radicals (2, 2-diphenyl-1-picrylhydrazyl and 3-ethylbenzothiazoline-6-sulfonicacid) called scavenging of radicals (Wootton-Beard et al. 2011). An administration of 8 ml/kg body weight/day beetroot juice lowered the protein oxidation, DNA damage, and lipid peroxidation in rats (Kujawska et al. 2009). Wootton-Beard and Ryan (2011) identified the increase in simulated digestion, as a function of antioxidant by the consumption of beetroot juice and also confirmed the juice components are structurally altered phytochemicals show similar function. However, the potential antioxidant activity of beetroot juice acting through a mechanism called scavenging radical species. The phytochemicals of beetroot juice inhibit the inflammatory diseases through signaling pathways (Tom et al. 2015). Pedro et al. (2014) proved the 32% lowered function of inflammatory enzymes lipoxygenase and cyclooxygenase by phenethylamine–betaxanthin and detalan. The antioxidant phytochemicals, iron, vitamin A, and vitamin B6 of beetroot juice can protect the liver from oxidative stress and inflammation and elevate its regular activity of detoxification.

The beetroot juice not only prevents the oxidative stress and blood pressure, it also lowers the anemia. Richness of iron in beetroot juice effectively improves the tissue oxygen supplementation and reduces the symptoms of anemia. The positive health effect of beetroot juice is due to the physicochemical composition of various components and their effective function against antioxidant stress. The role of beetroot juice in the maintenance of human health represented in many studies and is presented in Table 3.2.

### 3.2.3 Peels and Other Waste

The processing of agricultural products produces the largest waste in agro-based industries. One of such industries producing large amount of waste is beetroot processing units. The waste of beetroot used to produce the colorant possesses a potent antioxidant activity. The total tannins, polyphenols, vitamin C, β-carotene, and total carotenoids were measured in beetroot pulp waste (Shyamala and Jamuna 2010). Shyamala and Jamuna (2010) reported high amount of protein (13.23 mg/100 g), 220–250 mg total polyphenols, and 40–78% antioxidant activity in methanolic extracts of beetroot pulp waste. The new food products and ingredients for processed foods. One of such products derived from beetroot waste is the natural colorant for processed foods, which include the two colored antioxidant pigments –

**Table 3.2** Role of beetroot juice in exercise and energy performance in humans

| S. No. | Juice dosage | Performance | References |
|---|---|---|---|
| 1 | 500 ml | Maximum O2 consumption with high energy and work rate even after 15 days of consumption | Vanhatalo et al. (2010) |
| 2 | 500 ml | Strength increase exemplified with moderate oxygen consumption | Lansley et al. (2011a) |
| 3 | 500 ml | Oxygen consumption is reduced and 16% failure in high-intensity exercise | Bailey et al. (2010) |
| 4 | 500 ml | The power output for running significantly increased | Lansley et al. (2011b) |
| 5 | 500 ml | Increased strength with low consumption of oxygen during and after exercise | Bailey et al. (2009) |
| 6 | 140 ml | Maximum energy of 45% and 65% with low oxygen consumption. A speed of 1.2% recorded at 10 km running with a 2.1% increase of power output | Cermak et al. (2012a) |
| 7 | 750 ml | Increased high-intensity exercise with reduced perturbation of muscle hypoxia | Vanhatalo et al. (2010) |
| 8 | 500 ml | Increased energy with low oxygen consumption increased exercise tolerance | Kenjale et al. (2011) |
| 9 | 200 g beetroot | The running velocity is not significantly increased | Murphy et al. (2012) |
| 10 | 140 ml before 1 h of cycling | Elevates plasma nitrite, but no influence on cycling and heart rate | Cermak et al. (2012b) |
| 11 | 500 ml/day for 6 days | Increased intensity of rowing ergometer performance and later stages of exercise | Bond et al. (2012) |
| 12 | 500 ml/day | Increased energy with low oxygen consumption increased | Wilkerson et al. (2012) |
| 13 | 70 nmol/kg of body weight/day for 6 days | Lower oxygen consumption and hypoxia due to moderate exercise | Masschelein et al. (2012) |
| 14 | 500 ml/day for 6 days | No significant change in increased energy and low oxygen consumption | Christensen et al. (2013) |
| 15 | 500 ml/day for 7–12 days | Increased energy levels with improved tolerance for exercise | Kelly et al. (2013) |
| 16 | 70 ml before 2nd and 3rd of three performance trials | High energy with low oxygen consumption with significantly improved exercise performance | Muggeridge et al. (2013a) |
| 17 | 70 ml before 2nd and 3rd of three performance trials | High energy with low oxygen consumption with significantly improved study state exercise performance | Muggeridge et al. (2013b) |
| 18 | 70 ml, 140 mL or 0.28 L | High energy with low oxygen consumption with significantly improved exercise performance. No change in the physiological response during exercise | Wylie et al. (2013) |

called red-violet betacyanins and yellow-orange betaxanthins – that protect from degenerative diseases (Azeredo 2009). Unlike artificial colorants, natural ones play a crucial role in drinks and foods due to lack of side effects. Costa et al. (2017) developed a method to develop a colorant from the beetroot waste. They processed the waste by drying at 70 °C and obtained flour is rich with betalains having antioxidant activity. They were also reported that the colorant obtained in this process is stable until 20 days without altering its antioxidant activity. Moreover, the beetroot waste colorants are nontoxic and may hold antimicrobial activities along with nutritional value. Using red beetroot waste aqueous extract at room temperature, Girish and Arun (2018) developed single-crystalline, gold nano-plates comprising catalytic, nontoxicity, and biocompatibility activities which facilitate wide applications in diverse biological fields.

## 3.3 Antioxidant Properties of Beetroot Products

The root and green parts of beetroot can be used to prepare various commercial products. It is well known that roots of beet are exemplified with rich antioxidant components with a many health benefits. The green leaves and its petioles are used to prepare various products which are an excellent source of vitamins A and C, iron, calcium, manganese, potassium, folic acid, and fiber (Neha et al. 2017). A number of processed beetroot products are transported to all over the world. Pickles, salads, juices, sports drinks, and sugar are some the popular beetroot products. Besides these, the phenolic secondary metabolites of beetroot popularly known as betalains, a natural colorant, are used in the food industry. The presence of phenolic antioxidant compounds in the beetroot products increases the health benefits for humans, which include anti-inflammatory actions, resistance to peroxidation of lipids, against oxidation of low-density lipoproteins, and detoxification of chemicals in the liver (Georgiev et al. 2010; Reddy et al. 2005; Tesoriere et al. 2003; Zhang et al. 2013). The fresh products like halwa and lassi are the two products prepared from beetroot with addition of other ingredients which are energy and antioxidant rich (Neha et al. 2017).

The antioxidant properties and low fructose with high sucrose content in beetroot play an important role in the diet of athletes. Most available commercial products are juices and powders in the USA, Asian, European, and other countries. However, the available content of specified antioxidant compounds varies in the juice prepared from different varieties of beetroots (Wruss et al. 2015). Similarly, the beetroot products processed at home are shown changes in bio-accessibility and antioxidant properties (Burcu et al. 2016). The effective antioxidant role of beetroot extracts was also tested in the food industry (Vassilios et al. 2016). The red beet juices antioxidant activity was tested after thermal pretreatment in microwave (Slavov et al. 2013). Slavov et al. (2013) found that the microwave pretreatment of red beet juice yielded the highest total content of betalain (606.34 mg/100 g dry beetroot) and showed uppermost antioxidant activity (10832.4 μmol TE/I). In the same study, they found that pressed beet juice consisting of 321.47 mg betanin, 104.08 mg vulgaxanthin I, and 71.28 mg isobetanin per 100 g of dry matter. This antioxidant property of beetroot extracts/juices varies with the extraction solvent/processing method used for beetroot phenolics and also found a variation from species to species (Nahal et al. 2018).

## 3.4 Characterization of the Chemical Compound(s) Responsible for Antioxidant Properties

Beetroots are rich with various components, including phenolic and detailing compounds. Besides these compounds, beetroots consist of different mineral along with various nutritional components (Fig. 3.4a and b). Various studies focused to identify the components of beetroot, where they identified ferulic acid, vanillic acid, p-hydroxybenzoic acid, catechin, rutin, caffeic acid, and epicatechin belongs to phenolics, betacyanin (betanin and isobetanin), and betaxanthins (vulgaxanthin I) (Vulic et al. 2014). Clifford et al. (2015), Ninfali and Angelino (2013), Lidder and Webb (2013), and Guldiken et al. (2016) identified greatly active colored compounds such as betalains, ascorbic acid, carotenoids, polyphenols, saponins, nitrate, and flavonoids, and small amounts of glycine, folate, minerals, vitamins, and betaine. However, the constituents of beetroot have potent antioxidant activity and are becoming molecules for health and disease maintenance. The identified compounds belong to various categories and their structures were presented in Table 3.3 and Fig. 3.3**.**

Colored vegetables are the treasures for antioxidants. Beetroot consist of a large variety of biological compounds which acts against stress by activating the natural antioxidant system in humans. Due to the presence of antioxidants, the value of beetroot products is getting more attention for health care against diseases. A variety of beetroot antioxidants were identified in different studies with varied levels of oxidative stress release. About 1169 mg GAE of phenolics, 925 mg catechin equivalents of flavonoids, 854 mg pigments, and 325 mg ascorbic acid equivalents of DPPH in 1 L of beetroot juice was identified with a potential antioxidant activity (Fidelis et al. 2017). Identified compounds of beetroot and differently processed beet foods show varied antioxidant properties. The percentage of the antioxidant levels of chips, powder, cooked, and juice of beetroot is determined respectively as 95.70, 95.31, 85.79, and 80.48. Kathiravan et al. (2014) and Wootton-Bread and Ryan (2011) found that aglycone betanidine belonging to betanin possess great antioxidant activity by reducing the peroxidation of lipids. The varied forms of beetroot with difference of antioxidant properties may need attention to determine the complete picture of beetroot products and their protective role diseases and their health benefits.

**Table 3.3** Classification of different compounds identified and isolated from beetroot

| S. No. | Main category | Subcategory | Sub-subcategory | Subsequent categories |
|---|---|---|---|---|
| 1 | Phenolics | Phenolic acids | Ferulic acid and its conjugate derivatives | 5,5, 6,6-tetrahydroxy-3,3-biinodolyl Feruloyl glucose |
| | | | | β-d-fructofuranosyl-α-d-(6-o-(E)-feruloyl glucopyranoside) |
| | | Phenolic amides | N-trans-Feruloylhomovanillylamine | |
| | | | N-trans-Feruloyltyramine | |
| | | Flavonoids | Cochiophilin A, β-garin, β-vulgarin, Dihydroisorhamnetin, quercetin, rutin, tiliroside, astragalin, rhamnocitrin, rhamnetin, kaempferol | |
| | | Cyanidins, esculetin, peonidin, scopoletin, umbelliferone | | |
| 2 | Carotenoids | | | |
| 3 | Betalains | Betacyanins | Betanins | |
| | | | Isobetanins | |
| | | | Prebetanin | |
| | | | Neobetanin | |
| | | Betaxanthin | Vulgaxanthin I | |
| | | | Vulgaxanthin II | |
| | | | Indicaxanthin | |
| 4 | Nitrate | Nitric oxide | | |
| 5 | Ascorbic acid | Vitamin C | | |
| 6 | Saponins | Oleanolic acid, hederagenin aglycone, betavulgarosides I,II, III, IV, V, VI, VII, VIII, IX, and X | | |
| 7 | Ferulic acids | | | |
| 8 | Taurine | | | |
| 9 | Steroids/ Triterpenes | Beta- amyrin acetate, friedelin, boehmeryl acetate | | |
| 10 | Sesquiterpenoids | Ipomeamarone, 6-myoporol, 4-hydroxy dehydromyoporone | | |
| 11 | Alkaloids | Ipomine, calystegine B1, calystegine B2, calystegine B3, calystegine C1 | | |

## 3.5 Health Benefits

Sweetness due to the presence of high amounts of very low calories is the notable character of vegetable beetroot. They are popularized due to the potential of antioxidant activity along with nutritional value. Essentially, they carry minerals, vitamins, and different secondary metabolites collectively named as antioxidants. The health benefits of beetroot are because of presence of essential minerals and vitamins

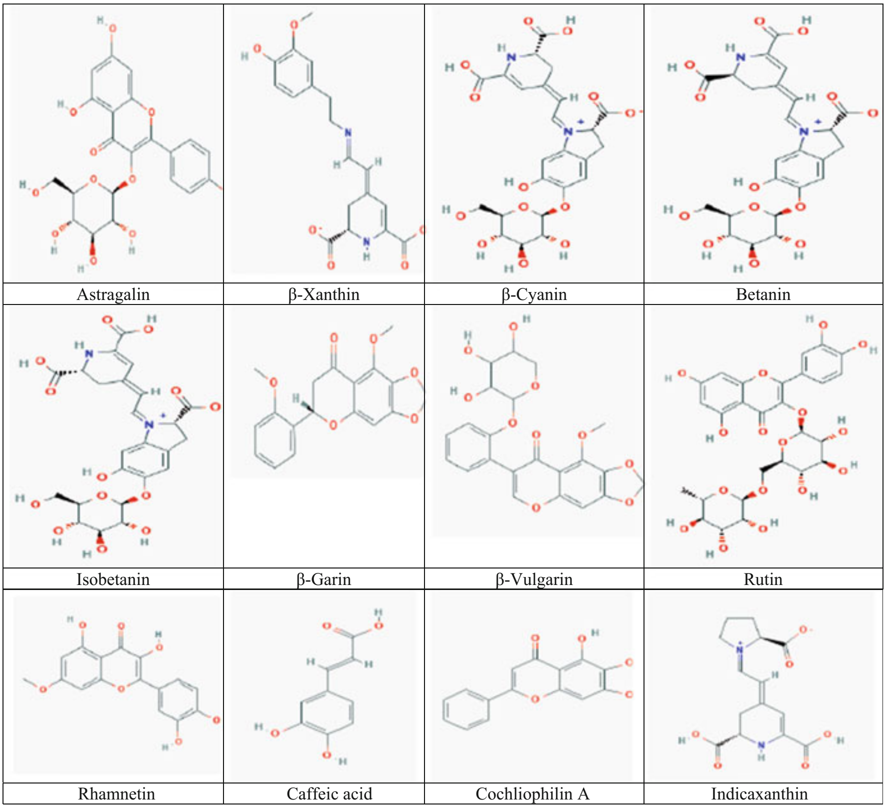


**Fig. 3.3** Beetroot phytochemicals and their structures

(Table 3.4). Antioxidant phytochemicals of beetroot play a crucial role to maintain good health (Table 3.4). The nutritional value of green tops of beetroot is notable and consists of calcium, iron, and β-carotene. The amount of different minerals and other contents are presented in the bar diagram (Fig. 3.4a and b).

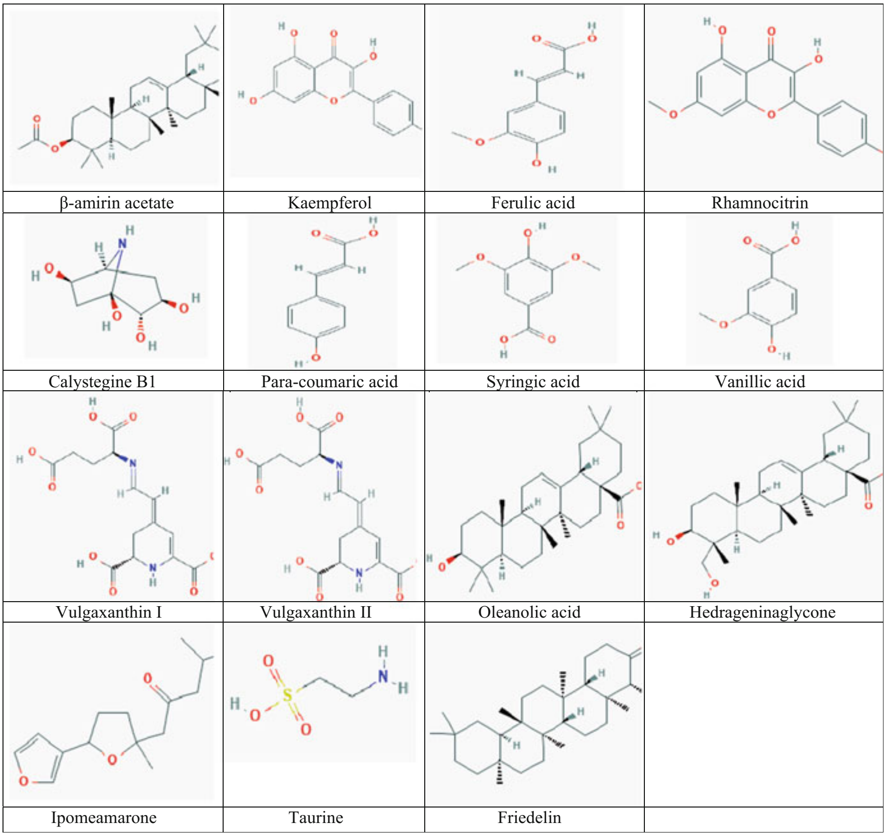


**Fig. 3.3** (continued)

## 3.6 Conclusion and Future Outlook

This chapter described the species, biology, and biological benefits of beetroot, including classification, available cultivars, nutritional, medicinal, and pharmacological activities. The antioxidant potential of beetroot and its products is due to presence of various bioactive compounds, including betalains, phenols, flavonoids, nitrates, fibers, vitamins, and minerals, which are naturally assimilated in the gut after consumption. The beetroot caters to the need of cellular response to oxidative

**Table 3.4** The antioxidant compounds, minerals, vitamins, and other constituents of beetroot and its role in the maintenance of human health

| S. No. | Antioxidants/minerals/ vitamins | Health benefits | References |
|---|---|---|---|
| 1 | Phytochemicals (ascorbic acid, phenolic acids, flavonoids and carotenoids) | Enhances immune function, reduction in oxidative stress and inflammation | Wootton-Beard and Ryan (2011), Kujala et al. (2002), Georgiev et al. (2010), and Al-Sheekhly (2011) |
| 2 | Betalains, betacyanins (betanin and isobetanin) | Important phytochemicals possessing antitoxic, antioxidant, and anti-inflammatory activity. Act as chemo-preventive agents for cancer | Frank et al. (2005), Kanner et al. (2001), John and Gary (2019), and Al-Sheekhly (2011) |
| 3 | Saponins (oleanolic acid, hederagenin aglycone, betavulgarosides I, II, III, IV, V, VI, VII, VIII, IX, and X) | Viricidal, hypolipidemic and hypoglycemic, antifungal and antimicrobial activity | Mroczek et al. (2012) and Lim (2016) |
| 4 | Steroid/triterpenes (β-amyrin acetate, boehmeryl acetate, friedelin) | Inhibits growth of oral mucosal, colon, and breast cancer. Anti-inflammatory, antioxidant, liver protection, antibacterial activities | Mroczek et al. (2012) and Lim (2016) |
| 5 | Sesquiterpenoids (Ipomeamarone 6-myoporol, 4-hydroxydehydro-myoporone) | Anti-inflammation, anti-tumorigenesis, prevents neurodegeneration, antimigraine activity, analgesic and sedative activities | Chadwick et al. (2013) |
| 6 | Alkaloid (Ipomine, calystegine B1, calystegine B2, calystegine B3, calystegine C1 | Anti-progestogenic and alterations in estrous cycle | Lim (2016) |
| 7 | Ferulic acid | Antioxidant, anti-inflammatory, anticarcinogenic, antiallergic, antimicrobial, hepatoprotective, antiviral, antithrombotic, vasodilatory effect and helps sperm protection | Kumar and Pruthi (2014) |
| 8 | Taurine | Reduces fat deposition, triglycerides, serum and liver cholesterol | Schalinske and Smazal (2012) |
| 9 | Nitrates | Maintains systematic blood flow and heart health and improves the | Satnam and Andrew (2012), Muggeridge et al. (2014), Tom et al. (2015), |

(continued)

**Table 3.4** (continued)

| S. No. | Antioxidants/minerals/ vitamins | Health benefits | References |
|---|---|---|---|
| | | performance of athletes by the elevated efficacy of mitochondria. Maintain cognitive and mental health of the brain | Rokkedal-Lausch et al. (2019), and Al-Sheekhly (2011) |
| 10 | Magnesium | Essential for maintenance of muscle, heart, nerve, and immune health. Participates in >300 biochemical reaction in the body | Petek et al. (2019), Kumar (2015b), Cardoso et al. (2017), and Al-Sheekhly (2011) |
| 11 | Copper | Supports bones and blood vessels, the immune system, and plays an important role in collagen formation | Petek et al. (2019), Kumar (2015b), Cardoso et al. (2017), and Al-Sheekhly (2011) |
| 12 | Phosphorous | Required for bones, teeth, and cell repair | Petek et al. (2019), Kumar (2015b), Cardoso et al. (2017), and Al-Sheekhly (2011) |
| 13 | Zinc | Required for normal growth, immune reactions, and wound healing | Petek et al. (2019), Kumar (2015b), Cardoso et al. (2017), and Al-Sheekhly (2011) |
| 14 | Sulfur | Component of structural and functional proteins | Cardoso et al. (2017) and Al-Sheekhly (2011) |
| 15 | Iron | Essential for energy metabolism of each and every cell of the body by carrying oxygen as a component of hemoglobin present in red blood cells. Reduces fatigue, shortness of breath, rapid heartbeat, dizziness, headache, etc. | Petek et al. (2019), Kumar (2015b), and Al-Sheekhly (2011) |
| 16 | Calcium | Mainly promotes bone growth and strength. Required for different metabolic aspects of the cell | Petek et al. (2019), Kumar (2015b), and Al-Sheekhly (2011) |
| 17 | Vitamin $B_6$ | Maintains health by involving in production of red blood cells and various cellular metabolic pathways | Tom et al. (2015), Hossam et al. (2018), Kale et al. (2018), and Al-Sheekhly (2011) |
| 18 | Folate (Vitamin $B_9$) | A crucial component of DNA and cell death | Tom et al. (2015), Hossam et al. (2018), Kale et al. (2018), and Al-Sheekhly (2011) |

(continued)

**Table 3.4** (continued)

| S. No. | Antioxidants/minerals/ vitamins | Health benefits | References |
|---|---|---|---|
| 19 | Vitamin A | Maintains improved vision and reduces night blindness | Tom et al. (2015), Hossam et al. (2018), Kale et al. (2018), and Al-Sheekhly (2011) |
| 20 | Vitamin C | A well-known antioxidant helps with immunity and skin health. Converts nitrite to nitric oxide | Tom et al. (2015), Lundberg et al. (2008), Kim-Shapiro and Gladwin (2014), Hossam et al. (2018), Kale et al. (2018), and Al-Sheekhly (2011) |
| 21 | Beet fibers and proteins | Improves digestion and lowers inflammatory bowel disease, thereby reduces the risk of heart disease, diabetes type 2, and colorectal cancer. Fibers are low in calories with high water content and moderate protein levels help in weight reduction | Salvin (2013), Threapleton et al. (2013), Otles and Ozgoz (2014), Joanne (2013), Yao et al. (2014), and Te Morenga et al. (2011) |

stress, free radical elimination, and its phytochemical formulations point to the importance of the inclusion of this plant as a dietary component in order to combat various metabolic disorders, neurodegenerative diseases, cancer, and inflammatory conditions, etc. Studies involving the effects of beetroot formulations and different bioactive compounds of beetroot on a significant number of health conditions could boost the food and therapeutic industry. A new unexplored direction for the elucidation and characterization of novel bioactive and functional compounds would be beneficial for scientific research on pharmacological potential of *Beta vulgaris* L. ssp. *vulgaris*, particularly as antiaging, anticancerous, anti-AIDS agent, and for enhancement of medical therapies in other human syndromes and other modern-day neurodegenerative disorders like Parkinson’s and Alzheimer’s.

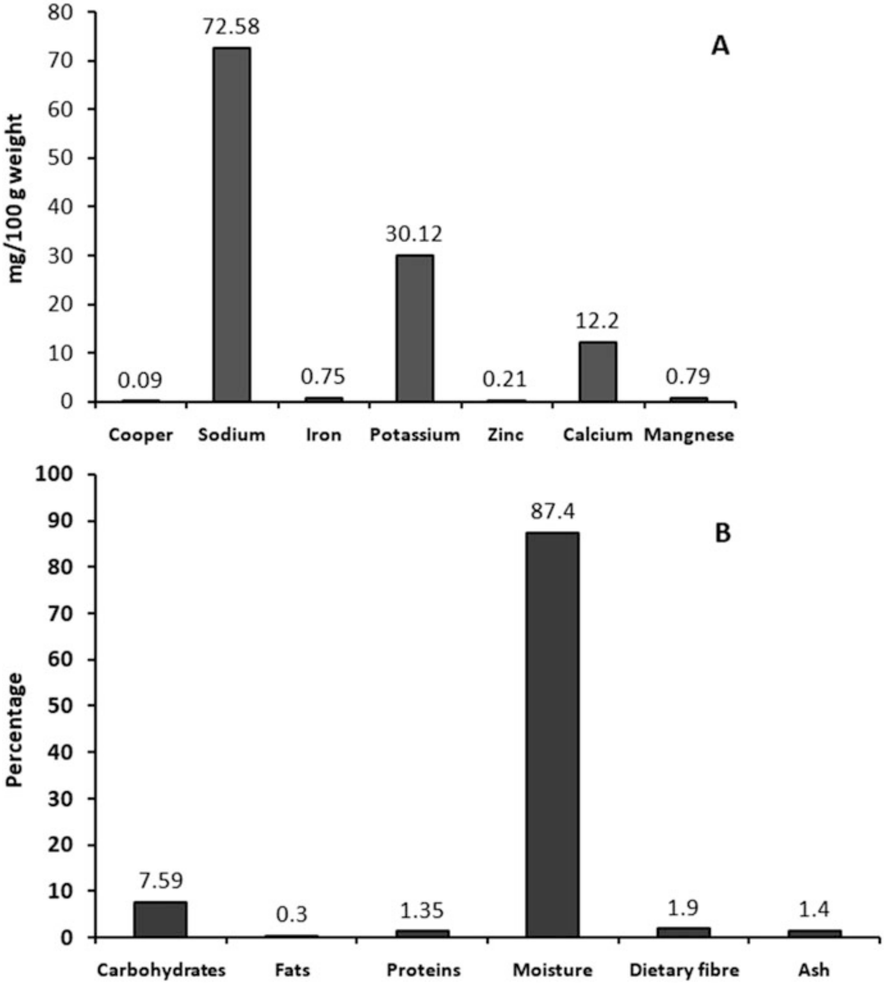


**Fig. 3.4 Different constituents of beetroot. (a). Minerals (b). Proximate composition.** (The data for graphs is obtained from data of Kale et al. 2018)

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# Lemongrass

# 4

Jyoti Gaba, Garima Bhardwaj, and Ajay Sharma

**Abstract**

Secondary metabolites (SMs) are known to have a wide range of therapeutic values. Large numbers of drugs are derived from these SMs. These naturally occurring SMs known to act as a potent source of antimicrobial, antiviral, anti-inflammatory, anticancer, and insecticidal agents. Aromatic plants are the prime source of variety of easily available SMs. Numerous classes of these SMs also act as powerful natural antioxidants. Antioxidants are the compounds that inhibit or slow down the oxidation of other molecules and help to cure the oxidative stress condition. Oxidative stress is the condition where the amount of free radicals in the body of organism exceeds the homeostatic balance of free radicals and indigenous antioxidant. This excess of free redials leads to various types of chain reactions that damage cells. These free radicals are the cause of more than hundred kinds of diseases in living beings. *Cymbopogon* is a genus of about 180 species of monocots grasses in a family of Poaceae (Gramineae). The species of genus *Cymbopogon* are rich source of naturally occurring antioxidants (such as phenolic acids, flavonoids, tannins, hydroquinone, terpenoids and fatty alcohols, etc.), and lemongrass (*Cymbopogon citrates*) is one of them. Further, the pharmacological applications of lemongrass are also

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well explored. Hence in the present chapter, we intend to discuss the botanical description, traditional uses, phytochemistry, antioxidant potential, health benefits, and potential economic importance of lemongrass.

**Keywords**

Lemongrass · Cymbopogon · Phytochemistry · Secondary metabolites · Antioxidants

## 4.1 Introduction

Aromatic medicinal plants are extensively used owing to their potent medicinal and nutritional properties (Sharma and Cannoo 2013; Joshi 2014). Medicinal aromatic plants are source of variety of biologically active secondary metabolites (SMs). These SMs can be categorized into various classes, namely, phenolic acids, tannins, flavonoids, alkaloids, terpenoids, saponins, steroids, glycosides, etc. (Sharma et al. 2018, 2019). All the classes of SMs are known to show a particular biological potential, just like alkaloids cure HIV infection, saponins have antifungal activity, tannins have antimicrobial activity, flavonoids have physically powerful anticancer activity, etc. (DellaGreca et al. 2009). Further, aromatic medicinal plants have diverse kind of volatile SMs, which are isolated from different parts of plants like roots, rhizome, stems, and flowers. The essential oils isolated from these aromatic plants mostly use for perfumery, food flavoring industries, aroma therapy, and various health benefits (Sharma and Cannoo 2013).

The World Health Organization (WHO) report revealed that the more than two-third of the world's population is largely dependent on the use of traditional medicine for their primary health care needs because of its relatively safe therapeutic results (Gopal et al. 2014; Sharma et al. 2018). Different parts of aromatic medicinal plants (flowers, roots, rhizomes, stems, leaves) as such or in the modified forms are used as nutraceuticals, food supplements, folk medicines, drugs, food additives, flavoring agents, herbicides, fungicides, etc. (Suhaib et al. 2011; Rahman et al. 2011). Hence, there is always a constant growth in their demand. On account of this, the aromatic medicinal plants play an important role in the life of the people particularly living in the tribes and remote areas by giving them both food and medicine (Chhetri et al. 2015). The plant families such as cupessaceae, apiaceae, asteraceae, lauraceae, piperaceae, lamiaceae, rutaceae, myrtacea, zingiberaceae, etc. are well known for their important and valuable bioactive SMs, and poaceae is one of them.

Cymbopogon is a multiregional genus belonging to significant essential oil–yielding family Poaceae (Gramineae) of monocots grass. The genus comprises of about 180 species, including varieties, sub-varieties, and subspecies. The Cymbopogon is a Greek name, composed of "kymbe" (boat) and "pogon" (beard), which refer to the flower spike arrangement of the species (Shah et al. 2011). It is widely distributed in tropical and temperate regions all around the world (Asia, Africa, Europe, and America) (Bertea and Maffei 2010). Many species of this genus are known to be a rich source of volatile essential oils and have been largely used in traditional medicine pharmaceuticals, perfumery, and cosmetics industries (Shah et al. 2011; Avoseh et al. 2015). The genus is native to tropical Asia and India. There are different species of genus Cymbopogon viz., *C. winterianus, C. flexuosus, C. schoenanthus, C. ambiguous, C. bombycinus, C. refractus, C. obtectus, C. nardus*, *C. citratus,* etc. that are growing in the different countries of world like China, India, Japan, Nepal, Malaysia, Sri Lanka, Thailand, Mali, Benin, Cameroon, Egypt, Ghana, Kenya, Nigeria, Zambia, Zimbabwe, Italy, the United Kingdom, Canada, Cuba, Mexico, the USA, Argentina, Brazil, Peru, Venezuela, Australia, Papua New Guinea, etc. Out of these species *C. citrates* (lemongrass) is most studied species of this genus, owing to its numerous ethnopharmacological applications (Shah et al. 2011; Avoseh et al. 2015).

Traditionally lemongrass is used to cure coughs, flu, headache, elephantiasis, leprosy, gingivitis, ophthalmic, pneumonia, arthritis, malaria, and vascular disorders (Manvitha and Bidya 2014). Lemongrass is also used to detoxify the liver, kidney, bladder, pancreas, and the digestive tract due to its good cleansing properties. It also helps to reduce the cholesterol, excess fats, uric acid, and various toxins in the body. It stimulates the digestion, lactation, blood circulation, and alleviates gastroenteritis and indigestion (Shah et al. 2011; Manvitha and Bidya 2014). Lemongrass has also known to show various pharmacological activities such as insecticidal (Kumar 2013), antidiabetic (Kumar 2013), anti-amoebic (Blasi et al. 1990), acetylcholinesterase inhibitory (Khadri et al. 2008), cytotoxicity, anti-trypanosomal, anti-plasmodial (Kpoviessi et al. 2014), anti-inflammatory (Francisco et al. 2011), antioxidant (Khadri et al. 2008), anti-HIV (Wright et al. 2009), larvicidal (Barreira et al. 2004), antiprotozoal (Pedroso et al. 2006), antinociceptive (Viana et al. 2000), dermatotoxicity (Carmo et al. 2013), anticancer (Thangam et al. 2014), antibacterial, antifungal, antifilarial, antimutagenicity, antidiarrheal, antimalarial, antimutagenicity, antihypoglycemic, etc. (Shah et al. 2011; Avoseh et al. 2015).

The previous studies have shown that the chemical diversity of various extracts and essential oils obtained from different parts of *C. citratus* varied in accordance with its geographical origin (Negrelle and Gomes 2007). The biological potential of different essential oils and extracts obtained from *C. citratus* may be attributed to the composition of different classes of SMs present in these essential oils and extracts. The various key classes SMs present in different essential oils and extracts of *C. citratus* are phenols (elemicin, catechol, hydroquinone etc.), phenolic acids (chlorogenic, caffeic, p-coumaric acid, etc.), flavonoids (luteolin, quercetin, kaempferol, apigenin, and their glycosides), steroids (β-sitosterol and fucosterol), fatty alcohols (hexacosanol and triacontanol), terpenoids (volatile: monoterpenes – neral, geranial, myrcene, limonene etc. and sesquiterpenes – caryophyllene, humulene, beta-eudesmol; non-volatile: triterpenoid – cymbopogonol and cymbopogone), tannins (hydrolysable tannins – proanthocyanidins) (Ansari et al. 1996; Negrelle and Gomes 2007; Shah et al. 2011; Avoseh et al. 2015).

The occurrence of medicinally important SMs in *C. citratus* and tremendous therapeutic potential of these SMs in food, cosmetics, aroma, pharmaceutical, and agrochemical industries allow us to write the present chapter in order to provide significant knowledge concerning this plant to scientific society.

### 4.1.1 Traditional Uses

*C. citratus* was widely used in different ancient medicinal systems to cure various kinds of illness. Some of the key traditional uses of lemongrass are summarized below (Shah et al. 2011; Avoseh et al. 2015):

- In Cuba, the hot water extract obtained from dried leaves is taken orally which act as a hypotensive for rheumatism and catarrh (Carbajal et al. 1989).
- In Argentina, the decoction prepared from leaves is taken orally with mate tea to cure empacho, sore throat, and as an emetic (Filipoy 1994).
- In Egypt, the hot water extract obtained from dried stems and leaves is taken orally as a diuretic and renal antispasmodic (Locksley et al. 1982).
- In Brazil, the tea prepared from leaves is usually used as analgesic, antipyretic, diuretic, sedative, antispasmodic, and anti-inflammatory (Leite et al. 1986; Souza-Formigoni et al. 1986).
- In USA, the hot water extract obtained from whole plant is used externally for healing bone fractures and wounds by Laotian Hmong peoples in Minnesota (Spring 1989).
- In Indonesia and Malaysia, the hot water extract prepared from whole plant is taken orally which act as emmenagogue (Quisumbing 1951).
- In Thailand, the fresh whole plant is eaten as a condiment and inhaled as a fragrance (Praditvarn and Sambhandharaksa 1950). The hot water extract prepared from whole dried plant is taken orally which act as stomachic, while the hot water extract obtained from dried root is taken orally to treat diabetes (Ngamwathana and Kanchanapee 1971).
- In India, the fresh whole plant is used to repel snakes. A few drops of essential oil mixed in hot water are taken orally to treat gastric troubles, while a few drops of essential oil mixed with lemon juice are taken orally to treat cholera. In cases of severe fever and headache, the hot water extract obtained from dried leaves is usually used during bathing. Further, a lemongrass tea is used as a sedative (Rao and Jamir 1982; John 1984).

### 4.1.2 Botanical Description and Taxonomical Classification

*C. citratus* is a fast-growing perennial grass having lemon-scented bluish-green leaves arising from sparingly branched rhizomes. It can grow up to 1 m height and 5–10 mm width. The species does not produce seeds. It has large number of bulbous stems. The leaves are glabrous, linear, long, tapering upward, and along the margins. It has nodding inflorescences with paired racemes of spirelets (Ross 1999; Jayasinha 1999). The taxonomical classification of lemongrass is as follow (Shah et al. 2011):

Kingdom: Plantae
Division: Magnoliophyta
Class: Liliopsida
Order: Poales
Family: Poaceae
Genus: Cymbopogon
Species: citratus

**Common Names** Hindi – Sera, Verveine; Chinese – xiang mao, Thailand – Ta-khrai; English – Lemongrass, Citronella, Squinant; USA – Citronella; Egypt – Lemongrass; Brazil – Capim-cidrao, Capim-santo; Ethiopia – Tej-sar; Indonesian – Sereh; Italian – Cimbopogone; Malaysia – Sakumau; Mexico – Zacate limon; Swedish – Citrongrass; Turkish – Limon out; Spanish – hierba limon or zacate de limón; French – citronelle or verveine des indes; Colombia – Limonaria; Argentina – Limonaria; Nigeria – Lemongrass; Cuba – Cana Santa; Costa Rica – Grass tea (Ross 1999; Jayasinha 1999; Shah et al. 2011; Avoseh et al. 2015)

**Synonym(S)** *Andropogon ceriferus* Hack, *Andropogon roxburghii* Nees ex Steud., *Andropogon citratus* DC. ex Nees, *Cymbopogon nardus* (DC. ex Nees) Roberty and *Andropogon nardus* subsp. ceriferus L. Hack (Ross 1999; Jayasinha 1999).

**Parts Used** Rhizome, stem, leaves, and whole plant (Avoseh et al. 2015).

### 4.1.3 Production: India and Worldwide

In world trade, the oil of lemongrass is generally known as Cochin oil, as about 90% of it is transported from Cochin port. The lemongrass is cultivated in various states of India, but the Indian state of Kerala has the monopoly in its production and export. The annual production of lemongrass in the world is around 1000 tons, with 16,000 ha area of cultivation (Skaria et al. 2006). The leading exporters of lemongrass are Guatemala with trading of about 250,000 kg/year and Russia with trading of about 70,000 kg/year (Anonymous 2012). In India, the annual production of lemongrass is around 250 tons with cultivated area about 4000 ha (Skaria et al. 2006).

In India, generally three species have been identified viz. *C. flexuosus* var. flexuosus also known as Malabar, Cochin, or East Indian grass; *C. pendulus* (Nees ex Steud) Wats, also known as Jammu lemongrass; and *C. citratus* (DC) Stapf., also known as American or West Indian lemongrass. It grows wild in all areas ranging from sea level to 4200 m of altitude. It is mainly cultivated in Kerala, Maharashtra, Madhya Pradesh, Uttar Pradesh, Uttarakhand, Bengal, Assam, Sikkim, and Jammu and Kashmir. The large-scale cultivation of lemongrass is done at Chinnar Wildlife Sanctuary situated in Western Ghats of India (Nair and Jayakumar 1999; Handa and Kaul 1997). The key cultivated varieties of lemongrass in India, which evolved by clonal selection are Sugandhi, Praman, Pragati, Kavery, Krishna, CKP-25, RRL16, GRL-1, RRL-39, SD-68 and SB-9 (Patra et al. 1999; Farooqi and Sreeramu 2001).

## 4.2 Antioxidant Potential

Free radicals are competent, independent existing molecular species with unpaired electrons. Oxygen- and nitrogen-containing reactive free radical species are known as reactive oxygen species (ROS) and reactive nitrogen species (RNS), respectively. In human body, free radicals and other ROS/RNS are produced during vital metabolic processes by xanthine oxidase, peroxisomes, inflammation, phagocytosis, arachidonate pathways, and ischemia/reperfusion injury (Ebadi 2001). Many exogenous sources are also responsible for the production of these reactive species in human body such as various kinds of radiations, ozone, cigarette smoke, air pollutants, industrial chemicals, certain drugs, and pesticides etc. (Bagchi and Puri 1998; Bhardwaj et al. 2019). Excessive ROS/RNS and free radicals can attack nitrogenous bases in nucleic acids, amino acid side chains in proteins, and double bonds in unsaturated fatty acids, resulting in oxidative stress which eventually lead to serious health problems and diseases (Rao et al. 2006). Therefore, maintenance of critical balance between the production and scavenging of free radicals is very important for proper functioning and well-being of human body (Rock et al. 1996).

Antioxidants are chemical substances which assist in combating and limiting damage caused by free radicals/ROS/RNS and oxidative stress. Antioxidants are broadly of two types: endogenous and exogenous. Endogenous antioxidants are produced inside the human body and include intracellular antioxidant enzymes, viz. superoxide dismutase (SOD), glutathione peroxidase (GPX), catalase (CAT) and nonenzymic substances, including ascorbic acid (vitamin C), α-tocopherol (vitamin E), β-carotene (provitamin A), and glutathione (GSH), while exogenous antioxidants are taken from outside and may be naturally occurring (polyphenolic acids, flavonoids, tannins, etc.) or synthetic ones (Mates et al. 1999; Glatthaar et al. 1986; Sokol 1988; van Poppel and Goldbohm 1995). Although cells can generate their own antioxidants, still there is always need to consume antioxidants as a part of healthy diet in order to tackle with oxidative stress conditions (Harasym and Oledzki 2014). Exogenous antioxidants from fruits, vegetables, and other medicinal plants promote endogenous antioxidant activity and hence contribute to the strengthening of defense mechanisms (Stahl and Sies 2005). Fruits, vegetables, and medicinal plants are a rich source of vitamins, minerals, and natural antioxidant phytochemicals like carotenoids, phenolic acids, polyphenols, flavonoids, and tannins. Owing to this, fruits, vegetables, and medicinal plants have held indispensable place in daily human diet. Moreover, the essential oils and various extracts of aromatic plants have been of great interest for their potent antioxidant potential (Miguel 2010).

Lemongrass is a commonly used plant in traditional medicinal system due to its promising pharmacological activities and has promising antioxidant potential (Leite et al. 1986; Shah et al. 2011; Avoseh et al. 2015).

### 4.2.1 Antioxidant Potential of Lemongrass

Studies conducted by different research groups throughout the world for determination of antioxidant potential of lemongrass gave varying results depending upon the growing region, condition of plant, sample preparation, part used, extraction procedure, and technique of analysis. Hydroalcoholic extract (60 μg/ml) of lemongrass was able to inhibit different radicals, namely, 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), hydroxyl, superoxide, nitric oxide up to different percent inhibition values of 85, 77, 70, 76, and 78%, respectively (Rao et al. 2009). Mansour et al. (2015) reported that the lemongrass collected from Egyptian region was found better for inhibition of linoleic acid oxidation (55.1%, $IC_{50}$ 1.0 mg/ml) as compared to that collected from Madina (36.3%, $IC_{50}$ 6.9 mg/ml). Cheel et al. (2005) observed a promising free radical scavenging activity (76%) resulting from the flavonoids content extracted from the aerial parts of *C. citratus* from Chile. It was concluded by Orrego et al. (2009) that the infusions are better than decoctions for extraction of antioxidant phytochemicals from lemongrass. Out of methanol and ethanol, latter is considered better as its extract was found more effective in DPPH and NO radical scavenging (Soares et al. 2013). Halabi and Sheikh (2014) found that 50% ethanolic extract of *C. citratus* had better DPPH radical scavenging potential (48.3%) compared to aqueous extract (45%). Acetone extract of lemongrass possessed 38.49 μg/ml $IC_{50}$ value in DPPH radical scavenging assay, 709.73 ± 6.21 mmol Fe(II)/g FRAP content, 37.32 ± 1.07 mg/EDTA/g chelating ability, 238.84 ± 3.57 μg/ml $IC_{50}$ value in superoxide radical scavenging assay, 535.16 ± 50.26 mg AAE/g of extract phosphomolybdenum value (Geetha and Geetha 2016). $IC_{50}$ values of different solvent extracts, viz. aqueous, 40% ethanol, 50% ethanol, 70% ethanol, 80% ethanol, and chloroform have been reported to be equal to 278 μg/ml, 191.97 μg/ml, 258.9 μg/ml, 79.44 μg/ml, 1140 μg/ml, and 1998.10 μg/ml, respectively (Halabi and Sheikh 2014; Falah et al. 2015; Sah et al. 2012; Lu et al. 2014). Varying antioxidant potential of different solvent extracts may be attributed to the presence of varying amount of phytochemicals (polyphenolics) in them. In a study conducted by Patel and Mehta (2006), dry lemongrass exhibited better antioxidant properties with high flavonoids and phenolic content as compared to fresh one.

Free radicals and oxidative stress are involved in an important pathophysiological mechanism of depression (Davies 1995). *C. citratus* (10 mg/kg) was found more effective antidepressant when compared with standard Imipramine in albino mice (Dudhgaonkar et al. 2014). Antioxidant effects of *C. citratus* were observed in terms of increased liver glutathione content in paracetamol-treated animals (Saenthaweesuk et al. 2017). Aqueous extract of lemongrass decreased serum lipid peroxidation in rats, contributing toward its antioxidant capacity (Somparn et al. 2018). *C. citratus* aqueous extracts (5% and 10%) also alleviated cis-platin-mediated oxidative damage (decrease in superoxide dismutase, catalase, and glutathione peroxidase activity) in rats (Arhoghro et al. 2014). Cardioprotective effects of lemongrass in doxorubicin-treated animals were observed by Ahmed and Ibrahim (2018). They reported that the pretreatment with lemongrass caused a significant decrease in ROS, malondialdehyde levels, and consequently increased total proteins as well as antioxidant capacity. The ethanolic extract of lemongrass helped in suppressing oxidative stress in Wistar rats screened for diabetic conditions (Ademuyiwa and Grace 2015). Various studies carried out by Jamuna et al. (2017), Sanadhya et al. (2014), Adesegun et al. (2013), Balakrishnan et al. (2014), Ojo et al. (2006), Dang et al. (2001), Lean and Mohammad (1999) and Baratta et al. (1998) also confirmed the antioxidant potential of lemongrass.

### 4.2.2 Lemongrass as Antioxidant in Food

Oxidation and free radical formation reactions are not limited to human body only. Many biological systems, living organisms, and even food products are accessible to oxidative damage. Food products particularly with high fat content are susceptible to atmospheric oxidation, resulting in rancidity and spoilage. Antioxidants are added to food stuffs to protect it from lipid peroxidation, to keep its texture and taste, and to assure consumption safety properties (Carocho et al. 2018). A variety of plant materials having high phenolic, flavonoid, carotenoid, and terpene content have been proved effective antioxidants as well as preservatives in food (Arabshahi et al. 2007; Martin et al. 2002).

#### 4.2.2.1 Lemongrass Essential Oil

The antioxidant effect of lemongrass oil (1.5%) in terms of total volatile nitrogen (TVN) and thiobarbituric acid (TBA) values in refrigerated minced beef (4 °C) during a storage period of 6 days has been confirmed by Salem et al. (2010). Similar use of lemongrass oil in 12 days cold storage (4 °C) of camel burger has been reported by Zaki et al. (2018). TBA and total volatile base nitrogen (TVBN) values were significantly increased with increase in time of storage and camel burger formulated with different concentrations of lemongrass oil (0.5, 0.75 and 1.0%) exhibited lowest values than untreated control. Alrefaie and Bostan (2017) also recommended the use of lemongrass essential oil (600 ppm) to increase the shelf life of cakes at room temperature. They reported that the peroxide value (PV) and TBA values of cake sample treated with lemongrass essential oil was significantly lower ($p > 0.05$) at the end of the storage (1 month) in comparison to control. Also, in the fatty acid profile obtained by Gas Chromatography (GC), sample containing lemongrass (600 ppm) exhibited lower percentage of palmitic acid (26%) when compared with control (33.6%). Petchsoongsakul and Pechyen (2012) characterized eugenol extracted from lemongrass essential oil as a substitute to butylated hydroxytoluene (BHT) for packaging of raw materials.

#### 4.2.2.2 Lemongrass Leaf Powder

The antioxidant potential of lemongrass leaf powder on refrigerated raw and cooked pork patties has been evaluated by Olorunsanya et al. (2010). Treatment of 200 g raw pork patties with different concentrations lemongrass leaf powder (0.5, 1.0 and 1.5%) decreased the thiobarbituric acid reactive substance (TBARS) in comparison to untreated reference as well as standard tocopherol (200 mg). Also, the preservative antioxidant effects of lemongrass were observed more in raw pork patties as compared to their cooked counterparts. Effectiveness of lemongrass leaves powder (2%) in reducing lipid peroxidation and increasing total phenolic content (TPC) of fresh and cooked chicken burgers during a storage (4 °C) period of 12 days was stated by Eldeeb and Mosilhey (2018). Lemongrass (0.5%, 1.0%, 1.5%, and 2.0%) containing uncooked chicken burger samples possessed less TBARS values (1.49, 0.81, 0.77, and 0.53) when compared with control (1.92). Chicken burger treated with 2% lemongrass exhibited higher level of TPC (112.23 ± 0.301 mg/100 g) than untreated control (44.32 mg/100 g). Also, the antioxidant activity of lemongrass leaves powder was found higher than that of α-tocopherol (Eldeeb and Mosilhey 2018).

#### 4.2.2.3 Lemongrass Leaves Extract

Hydroalcoholic (70%) leaves extracts obtained from *C. citratus* (using conventional and ultrasonic method) were found to possess high antioxidant activity in stored chicken sausages (Boeira et al. 2018). In another study, Kanatt et al. (2014) reported that the aqueous extract of lemongrass leaves (0.1%) showed antioxidant preservative effects on radiation-processed minced chicken meat during 10 days of chilled storage. The antioxidant potential was monitored in terms of TBARS values as γ radiation, which was given at a dose rate of 2.5 k Gy/h accelerated lipid peroxidation (Ahn et al. 2000). Aqueous lemongrass extract (0.1%) containing irradiated chicken meat sample had significantly lower TBARS value proposing that it successfully retarded the lipid peroxidation during storage. The extract was also able to protect DNA from radiation (500 Gy)-induced damage by protecting the supercoiled form of DNA in comparison to control. Further, the $IC_{50}$ value of lemongrass extract was recorded as 90.3 mg/ml in comparison to standard BHT (25.2 mg/ml) in DPPH radical scavenging assay. Falah et al. (2015) studied the application of lemongrass leaves extract for prevention of soybean oil oxidation. The oxidative stability of dry air (110 °C) exposed soybean oil, when treated with ethanol (70%) extract of lemongrass, was found to be 1.19 in comparison to sample having soybean oil with BHT (1.53). The addition of aqueous and methanolic lemongrass leaves extract to refrigerated chicken patties (4 °C) caused reduction of lipid peroxidation, monitored in terms of TBARS values on 9th day of storage (0.39 mg malondialdehyde/kg sample) in contrast to control (0.44 mg malondialdehyde/kg sample) (Ibrahim and Abu Salem 2013). Methanol extract possessed higher antioxidant potential than aqueous extract with antioxidant value of 11.45 ± 0.020 mgGA/g) and 33.56 ± 0.025 mg BHT/g. Abd-El Fattah et al. (2010) used lemongrass as a conventional chemical preservative for storage of refrigerated yoghurt at 5 °C. Owing to the effectiveness of lemongrass as a significant natural antioxidant preservative, it can conveniently replace synthetic antioxidants in food industry.

#### 4.2.2.4 Formulations Having Lemongrass

Herbal infusions and teas are beneficial to human health because of their high phenolic, flavonoid content and hence have high antioxidant potential (Moraes-de-

Souza et al. 2008). Hot percolations of lemongrass tea from five different locations in southern Ghana possessed phenolics (2.6–7.3 mgGAE/g) and flavonoids (6.9–12.9 μg/g QE). Owing to this lemongrass tea had high total antioxidant capacity (65.4–81.3%) (Godwin et al. 2014). Temperature has pronounced effects on extraction of phytochemicals as indicated by low phenolic (1.3–4.7 mgGAE/g) and flavonoid (6.9–11.3 μg/g QE) content of cold percolations. Dzah (2015) developed a tea formulation by taking herbs "Srenunum" (*Lippia multiflora*) and lemongrass (*C. citratus*) with a medicinal mushroom "Reishi" (*Ganoderma lucidum*) in ratio 5:3:2. This tea formulation exhibited significantly higher antioxidant power than a known control Lipton yellow label. Lemongrass aqueous extract also increased the TPC and antioxidant potential of a mixed beverage having lemon juice and soymilk powder (Kieling and Prudencio 2019). A beverage with 50 ml/L of lemongrass aqueous extract, 1.25 g/L of lemongrass essential oil mixed in 16 g/L of soymilk powder exhibited higher DPPH scavenging activity (109.37 μgTE/ml), ABTS scavenging activity (381.89 μgTE/ml), and phenolic content (22.11 μg GAE/ml) as compared to beverage without lemongrass extract and lemongrass essential oil. *Nefang* is a polyherbal formulation of mango (*Mangifera indica*), guava (*Psidium guava*), papaya (*Carica papaya*), lemongrass (*C. citratus*), sweet orange (*Citrus sinensis*), and clove basil (*Ocimum gratissimum*) used for the treatment of malaria. Rats treated with *Nefang* showed increased levels of triglycerides, superoxide dismutase, and catalase confirming the antioxidant potential of this polyherbal product (Tarkang et al. 2013). A herbal mixture having 12.5% lemongrass, 12.5% curry leaves (*Murraya koenigii*), 12.5% turmeric (*Curcuma longa*), and 62.5% ginger (*Zingiber officinale*) was found to have a synergistic action on antioxidant activity with DPPH radical scavenging activity value of 88.38% (Poh et al. 2018). A herbal ice cream containing 10%, 15%, and 20% lemongrass was prepared by Chanmchan et al. (2017) exhibited high antioxidant activities as compared to control formula. Meena Anand et al. (2011) suggested the use of lemongrass oil as mouth wash for antioxidant effects. The superoxide dismutase levels of saliva and gingival crevicular fluid were increased after administration of lemongrass oil in all treatments. Efficacy of gel prepared from lemongrass essential oil as an adjunct to scaling and root planning for the treatment of chronic periodontitis was evaluated by Warad et al. (2013). Antioxidant activity of lemongrass gel resulted in increased tissue healing response, which further prevented the tissue destruction. Gargling with 2% and 4% lemongrass essential oil solutions increased the glutathione (GSH), nonenzymatic antioxidant found in cells, levels of saliva in gingivitis patients (Susanto et al. 2010). Dany et al. (2015) also concluded similar results in a study conducted to determine the efficacy of 0.25% lemongrass oil mouth wash.

#### 4.2.2.5 Products/Materials from Lemongrass

Silver nanoparticles prepared by using lemongrass showed ABTS radical scavenging activity of 70.12% at a concentration of 500 μg/ml with and $IC_{50}$ value of 30.60 μg/ml. Microencapsulated lemongrass extract (25%) in β-cyclodextrin at 120 °C exhibited high phenol content value (34.64 mg/100 g) and hence high antioxidant activity. This powder form of microencapsulated lemongrass extract was able to retain its stability over high oxygen contact and high temperature (Naufalin et al. 2019). Mishra et al. (2018) fabricated lemongrass essential oil–loaded composites of cellulose nanofibers–polyethylene glycol and suggested that these composite systems retain the properties of pure essential oil. Total phenolic and total antioxidant content of composite system ranged between 104–670 μg GAE/mg and 3.5–63.1 μg AAE/mg of lemongrass composite, respectively. These studies propose that fabricated essential oil composites may find applications in food storage and indoor air quality improvement.

### 4.2.3 Antioxidant Potential of Some *Cymbopogon* Varieties Other Than *C. citratus*

Khadri et al. (2010) measured the antioxidant capacity of *C. schoenanthus* shoots collected from three different locations of South Tunisia. Proanthocyanidin-rich extract of plant variety obtained particularly from desert region possessed highest antioxidant potential with $IC_{50}$ value of 50.52 mg/ml in β-carotene/linoleic acid bleaching test. *C. schoenanthus* essential oil (5%) obtained by hydrodistillation of plant collected from Egypt exhibited promising DPPH radical scavenging activity (32.28 mmol AAE, $IC_{50}$: 401.67 μg/ml) (El-Shennawy and Abozid 2017). Lower $IC_{50}$ value of methanolic extract (48.66 μg/ml) of C. *proximus* obtained from Egypt as compared to its essential oil (998.47 μg/ml) suggested the better DPPH radical scavenging action of the former (Selim 2011). In another study conduct by Wibowo et al. (2018), the essential oil of *C. nardus* collected from Lembang, West Java, was found to be very strong antioxidant with DPPH radical $IC_{50}$ value of 2.405 μg/ml.

## 4.3 Phytochemical Composition of *C. citratus*

Lemongrass has been well known for its volatile and nonvolatile SMs. The composition of these SMs varies depending upon their geographical origin. Terpenoids (volatile and nonvolatile), steroids, polyphenolics, flavonoids, tannins, and fatty alcohols are the key classes of SMs present obtained from lemongrass. These classes of SMs are mainly responsible for various ethno-pharmacological applications of lemongrass (Ansari et al. 1996; Negrelle and Gomes 2007; Shah et al. 2011; Avoseh et al. 2015). Figure 4.1 presents the structures of prime SMs isolated from lemongrass.

**Flavonoids** Various researcher isolated different flavonoids from *C. citratus*, luteolin, luteolin 7-O-glucoside (cynaroside), apigenin, quercetin, kaempferol, 2″-O-rhamnoside isoorientin, isoscoparin, swertiajaponin, and orientin were the major flavonoids isolated from lemongrass (Matouschek and Stahl 1991; Miean and Mohamed 2001; Cheel et al. 2005; Avoseh et al. 2015).

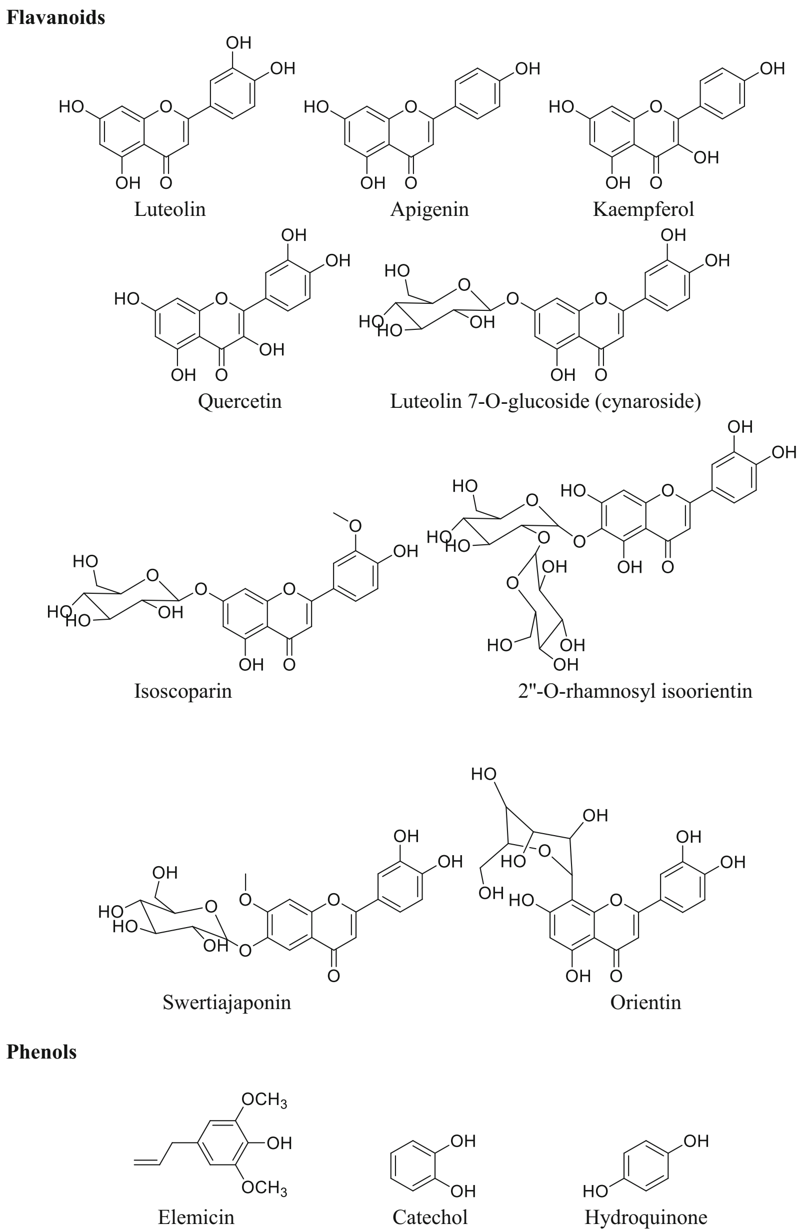
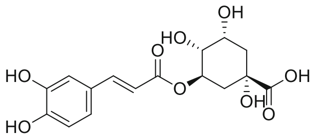
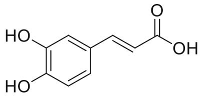



**Fig. 4.1** Structures of prime SMs isolated from lemongrass

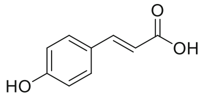
**Phenolic acids**



Chlorogenic acid

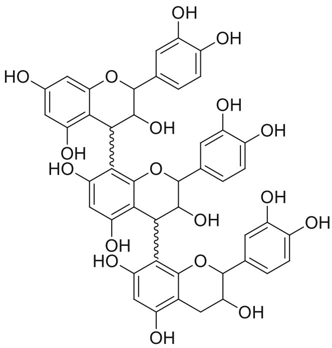


Caffeic acid



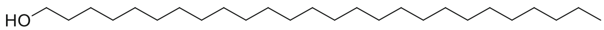
p-Coumaric

**Tannins (hydrolysable tannins)**

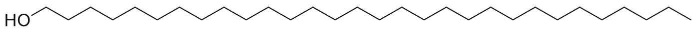


Proanthocyanidin

**Fatty alcohols**

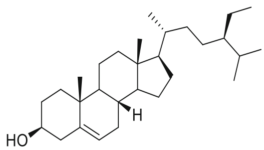


Hexacosanol

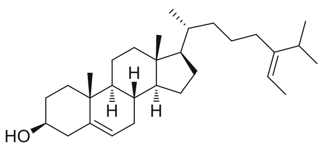


Triacontanol

**Steroids**



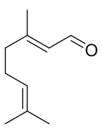
β-Sitosterol



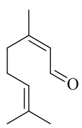
Fucosterol

**Terpenoids**

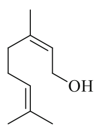
**A) Voletile teprenoids - a) Monoterpens**



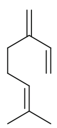
Geranial (Citral a)



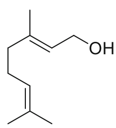
Neral (Citral b)



nerol

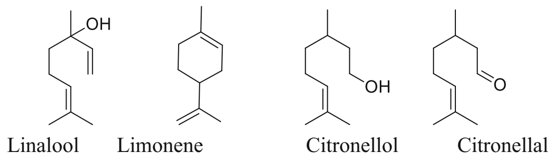


Myrcene

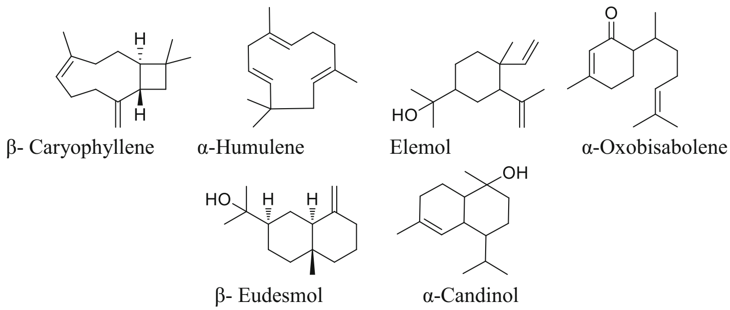


Geraniol

**Fig. 4.1** (continued)




b) **Sesquiterpens**




B) **Non-voletile terpenoids – Triterpenoids**

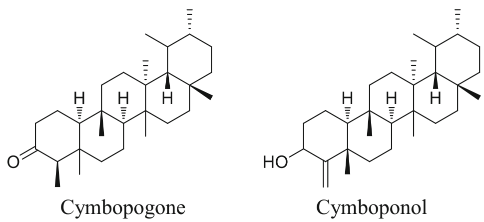



**Fig. 4.1** (continued)

**Polyphenolics** The key polyphenolics isolated from lemongrass comprises of phenols such as elemicin, catechol, hydroquinone, and phenolic acids like caffeic, chlorogenic, and *p*-coumaric acids (Faruq 1994; Matouschek and Stahl 1991).

**Tannins** Many reports in literature revealed the presence of tannins (by qualitative test) in the lemongrass (Edeoga et al. 2005; Aftab et al. 2011; Avoseh et al. 2015). Figueirinha et al. (2008) reported the presence of 10 mg DW (dry weight) of hydrolysable tannins (proanthocyanidins) in lemongrass.

**Fatty Alcohol and Steroids** Hexacosanol and triacontanol were the prime fatty alcohols, while β-sitosterol and fucosterol were the leading steroids reported in lemongrass (Olaniyi et al. 1975).

**Terpenoids** The literature revealed that the composition of volatile terpenoids phytochemicals of lemongrass essential oils varies depends on the method of extraction, genetic differences, part of the plant used, age/stage of maturity, season of harvest, and geographical origin (Idrees et al. 2012; Ewansiha et al. 2012). Regardless of these variations monoterpenes such as myrcene, neral (citral b), nerol, geranial, geraniol (citral a), linalool, limonene, citronellol, citronellal, and diterpenes like β-caryophyllene, α-humulene, elemol, α-oxobisabolene, β-eudesmol and α-candinol were the major terpenoids present in the essential oils isolated from lemongrass (Shah et al. 2011; Piarua et al. 2012; Farhang et al. 2013; Ranitha et al. 2014; Pinto et al. 2015; Avoseh et al. 2015). Further, nonvolatile triterpenoids isolated from lemongrass extract were cymbopogone and cymbopogonol (Ansari et al. 1996).

**Minerals** Joy (2003) reported that the lemon or spent grass contained N (0.74%), K (2.12%), P (0.07%), S (0.19%), Mg (0.15%), Ca (0.36%), Zn (35.51 ppm) Mn (155.82 ppm), Fe (126.73 ppm) and Cu (56.64 ppm).

## 4.4 Phytochemicals Responsible for Antioxidant Properties and the Pathways Involved in the Biological Activities

Antioxidants are classified into two types: primary and secondary. Primary antioxidants donate hydrogen atom to a radical, resulting in a more stable radical. On the other hand, secondary antioxidants decrease the rate of free radical formation via inhibition of radical reactions initiating enzymes (NADPH oxidase, peroxidase, xanthine oxidase), deactivation of singlet oxygen, and absorption of UV radiation (Singh and Singh 2008). In order to determine the antioxidant activity of plant-based materials, direct and indirect methods are being used. Direct methods include the effect of antioxidant on oxidative degradation of lipids, oils, blood plasma, DNA, proteins, and low-density lipoproteins of testing system. Whereas, indirect methods (DPPH assay, ABTS assay, TE antioxidant capacity (TEAC), ferric reducing/antioxidant power (FRAP) assay, reducing power, chelating ability, hydroxyl radical scavenging, superoxide anion scavenging, etc.) determine the potential of antioxidant to scavenge some free radicals, which are not related to actual oxidative degradation (Roginsky and Lissi 2005).

Oxidation of lipids by free radicals generate hydroperoxides as intermediates, which further decompose to give secondary products like alcohols, aldehydes, ketones, alkoxy radicals, and formic acid (Miguel 2010). Antioxidant potential is determined by measuring the substrate (oils, fats or linoleic acid, methyl esters of fatty acids) and oxidant consumption, or by estimating the intermediates and final products formed using five methods, namely, peroxidation evaluation by ferric thiocyanate, β-carotene bleaching test, TBARS assay, aldehyde/carboxylic acid assay, and formic acid measurement (Miguel 2010). Chemical processes involved in free radical scavenging reactions are based either on hydrogen atom or single electron transfer (Miguel 2010).

Fruits, vegetables, and aromatics plants produce chemicals required for their growth as well as for defense against predators and pathogens. These biologically active chemical species, namely, polyphenols (flavonoids, phenolic acids), terpenoids (carotenoids and noncarotenoids), thiols (glucosinolates, allylic sulfides, indoles) etc. are called phytochemicals (Vasanthi et al. 2009). Owing to the presence of phytochemicals, fruits, vegetables, and herbs exhibit protective action against free radicals and ROS/RNS. These free radicals and ROS/RNS are responsible for various kinds of diseases in human beings (Ames et al. 1993; Toniolo et al. 2001; Sharma and Cannoo 2016, 2017). Researches carried out by various authors (Sies 1997; Fukumoto and Mazza 2000; Valko et al. 2007; Prakash and Gupta 2009; Sharma and Cannoo 2017) have revealed that antioxidant potential of plants may be attributed to the presence of phytochemicals such as polyphenols, flavonoids, tannins alkaloids, carotenoids, lignins, terpenoids, vitamins, etc. These plant-based chemicals inhibit lipid oxidation, reduce rancidity, and help in maintaining the nutritional value and shelf life of food samples (Promila and Madan 2018). Antioxidant potential of plant extracts is due to the synergistic action of above-mentioned phytochemicals (Kanatt et al. 2014). These natural antioxidants mainly perform following functions (Karadag et al. 2009):

- Prevent free radical and ROS/RNS generation
- Prevent free radical and ROS/RNS access to cell membranes
- Act as chemical traps to absorb electrons and quench free radicals
- Enhance action of catalytic enzymes, viz. SOD and CAT
- Bind to metal ions to prevent generation of free radical and ROS/RNS
- Scavenge and destroy free radical and ROS/RNS by chain breaking

Polyphenolic compounds interrupt the oxidation of lipids by inhibiting free radical chain reaction, consequently preventing production of hydroxyl free radical as well as other secondary products such as aldehydes, ketones, alcohols, malondialdehyde, etc. (Johnston et al. 2005; Ozen et al. 2011). Polyphenolic compounds being better donors of electrons and hydrogen atoms help in stabilization of radical via delocalization (Djenane et al. 2012). Also, due to the presence of hydrophobic benzenoid ring and hydrogen-bonding ability (through hydroxyl groups), polyphenolic compounds interact strongly with proteins. By virtue of these interactions, polyphenolics are capable of inhibiting radical generating enzymes, namely, xanthine oxidase, lipoxygenase, cytochrome $P_{450}$ isoforms, etc. (Cos et al. 1988; Parr and Bolwell 2000). Further, redox properties of polyphenolics and flavonoids help in absorption, neutralization, and quenching of peroxides and owing to this polyphenolics and flavonoids are mainly responsible for strong antioxidant potential of lemongrass extracts and essential oils (Jamuna et al. 2017). Geetha and Geetha (2016) have confirmed the fact that radical scavenging activity of lemongrass depends upon the extent of conjugation and degree of hydroxylation of phenolic compounds. Further, number of hydroxyl groups and phenolic structure play an important role in radical scavenging and metal chelation of antioxidants (Pazos et al. 2005; Kanatt et al. 2014; Jamuna et al. 2017). Shan et al. (2005), Khadri et al. (2010), and Thorat et al. (2017) have also concluded that antioxidant potential of lemongrass is due to the presence of polyphenolic compounds in it.

Tapia et al. (2007) described that *C. citratus* shoots flavonoid contribute less (28.6%) as compared to total phenolics (49.7%) toward radical scavenging activity. Contrary to this result, Cheel et al. (2005) have reported 76% contribution of flavonoids to antioxidant activity of lemongrass collected from Chile. Figueirinha et al. (2008) have confirmed that flavonoid and tannin fractions of lemongrass extract were more effective radical scavengers as compared to phenolic acid fractions. Due to low redox potential and high electron-donating capacity, flavonoids possess efficient radical scavenging properties (Pannala et al. 2001; Rice-Evans et al. 1997; Kieling and Prudencio 2019). Flavonoids are also known to react with myeloperoxidase (MPO), in the presence of hydrogen peroxide, consequently preventing the reaction of $NO_2$ with low density lipoproteins and hence retard the lipid peroxidation (Nambiar and Matela 2012). Some authors have reported antioxidant action of flavonoids via suppression of plasma cholesterol concentrations (Almoosawi et al. 2010; Anila and Vijayalakshmi 2000). The configuration and substitution of hydroxyl groups has a significant impact on radical scavenging activity of flavonoids (Kelly et al. 2002; Pandey et al. 2012). Chelation of metal ions with at specific hydroxyl groups (Fig. 4.2) of different rings of basic flavonoid structure is an important mechanism of free radical inhibition (Van Acker et al. 1996; Kumar and Pandey 2013; Mishra et al. 2018). Halabi and Sheikh (2014), Geetha and Geetha (2016), Eldeeb and Mosilhey (2018), and Sari et al. (2017) have stated the antioxidant activity of lemongrass through chelation/deactivation of transition metal ions, consequently inhibiting the decomposition of hydroperoxides as well as Fenton reaction.

Among three C-glycosyl flavonoids, viz. isoorientin, swertiajaponin, and isoorientin 2″-O-rhamnoside isolated from lemongrass leaves, isoorientin has been found to possess considerable antioxidant action through inhibition of low-density lipoprotein oxidation (Orrego et al. 2009). Campos et al. (2014) have also confirmed the compounds, namely, chlorogenic acids (VIII), isoorientin, and swertiajaponin in lemongrass to be responsible for antioxidant activity via alleviation of $Cu^{+2}$-induced low-density lipoprotein oxidation. Other minor derivatives of luteolin and apigenin

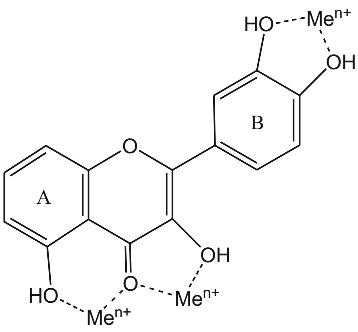



**Fig. 4.2** Chelation of metal ions with specific hydroxyl groups of basic flavonoid structure

were also speculated for contribution in antioxidant potential of lemongrass (Campos et al. 2014).

Antioxidant potential of lemongrass essential oil is related with the presence with monoterpene hydrocarbons, oxygenated monoterpene, and sesquiterpenes which help in breaking free radical chain reactions (El-Shennawy and Abozid 2017; Tepe et al. 2007; Yanishlieva et al. 1999; Foti and Ingold 2003). Synergistic action between terpenes and other antioxidants such as rutin and α-tocopherol is also an interesting feature of antioxidant mechanism (Grabmann 2005). Vyshali et al. (2016), Ruberto and Baratta (2000) attributed the antioxidant activity of *C. citratus* essential oil to synergistic action of terpenoids namely neral, geranial, and myrcene. Warad et al. (2013) have concluded that monoterpene such as citral and citronellal contribute to antioxidant activity of lemongrass. Essential oils having high content of phenolic compounds (like thymol, carvacrol, eugenol, etc.) possess high antioxidant properties (Lambert et al. 2001; Bagamboula et al. 2004). These components increase the oxygen absorbance and hydroxyl radical scavenging activity of plant tissue (Wang et al. 2008).

## 4.5 Health Benefits

Lemongrass, a nervine, is considered as a tonic for maintaining well-being of nervous system. It activates the mind and assists in countering neuronal disorders such as nervousness, convulsions, and vertigo. It is used in therapeutic baths with a purpose of calming the nerves and reducing the signs of fatigue and anxiety caused by stress (Goes et al. 2015; Costa et al. 2011a, b). It is also considered as a useful herb for relaxing muscles, nerves for inducing sleep and curing insomnia. Blanco et al. (2009) has explored the sedative and hypnotic effects of lemongrass for increasing sleep duration. The antioxidant properties of lemongrass aid in protection of body cells from free radicals/ROS/RNS and facilitate regeneration of cells (Patnaik et al. 1997). It is also effective in prevention of cancer cell growth without any harmful effects on healthy cells. Dudai et al. (2005) have studied and justified the inhibiting effect of citral, a constituent of lemongrass, on growth of hepatic cancer cells during initial stages. Citral has also shown antiproliferative effect in delaying the growth and induction of apoptosis of cancer cells responsible for breast cancer (Ghosh 2013; Philion et al. 2017).

Lemongrass has been found to possess anti-hypercholesterolemic and anti-hyperlipidemic properties (Kumar et al. 2011; Lee et al. 2018). It assists in reduction of blood cholesterol and supports maintaining healthy cholesterol levels (Costa et al. 2011a, b). Regular consumption of lemongrass prevents lipid accumulation and promotes unhindered blood flow in blood vessels, thereby reducing the risk of various heart diseases (Kumar et al. 2011). Citral, main constituent of lemongrass, reduces buildup of abdominal fat, encourages the utilization of stored energy resulting in prevention of diet-produced weight gain (Modak and Mukhopadhaya 2011). Olorunnisola et al. (2014) has revealed that lemongrass increases the body metabolism and therefore can be used effectively for control of obesity. In addition to this, lemongrass has been found to possess diuretic properties and aid in flushing and cleansing of harmful toxins from body (Nakamura et al. 2003). Diuretic property of herbs helps in sustaining digestive health by increasing the frequency and quantity of urination (Wile 2012). Use of lemongrass is also beneficial in alleviating gastro-intestinal disorders and inflammation thereby relieving from constipation, ulcerative colitis, ulcers, nausea, diarrhea and stomach aches (Fernandes et al. 2012). Due to its antimicrobial activity, lemongrass essential oil is capable of fighting stomach infections caused by pathogens *Helicobacter pylori* and *Escherichia coli* (Ohno et al. 2003). Adukwu et al. (2012) have confirmed the antibiofilm capacity and usefulness of its essential oil against infections caused by *Staphylococcus aureus*. The antimicrobial properties of lemongrass make it an effective herb for treatment of infections like scabies, ringworm, and urinary tract infections (Silva et al. 2008). Abe et al. (2003) have also proposed the healing effects of lemongrass on various dermatological yeast infections and oral and vaginal candidiasis via inhibition of growth of pathogens.

The analgesic properties lemongrass provides relief from headache, migraine, and rheumatism (Meenapriya and Priya 2017). When applied topically, it improves blood circulation (Kamkaen et al. 2015) and can be useful for treating spasms, sprains, backaches, muscle cramps, bruises, internal injuries, dislocations, etc. Another heath benefit of lemongrass is seen in its cleansing effect on lymphatic congestion which soothe the swelling and provides relief from edema (Boukhatem et al. 2014). Owing to its effectiveness in lowering fever, it also referred to as “fever grass” (Toungos 2019). In Ayurvedic medicinal system, antipyretic and diaphoretic properties of lemongrass are extensively explored for curing fevers through sweating (Gbenou et al. 2013; Toungos 2019). Modak and Mukhopadhaya (2011) have studied type-2 diabetes managing properties of lemongrass. Its constituent citral helps in maintaining optimal insulin levels and develops the glucose tolerance in body by enhancing energy dissipation and insulin sensitivity.

Antiseptic and astringent properties of lemongrass makes it an effective cleansing agent and skin care tonic for oily and acne prone skin through strengthening, sterilizing, and toning of skin tissues (Narayan and Maheshwari 2017). It is also used for tightening and uplifting of loose skin. Lemongrass improves blood circulation and is used in making deodorants (Mathew et al. 2017) and perfumes (Mane et al. 2015). Studies conducted by various authors (Oyedele et al. 2002; Baldacchino et al. 2013) have also confirmed the mosquito repellent, antiprotozoal, and antimalarial properties of lemongrass essential oil. Various pet-grooming products like shampoos having lemongrass are commercially available due to its repellent effects on ticks and lice. Doran et al. (2009) have suggested the use of its oil for air disinfection. It is also having protective hydrophobic properties for preservation of palm leaf manuscripts from bacterial damage by preventing humidity loss and providing the required moisture (Toungos 2019).

## 4.6 Conclusion

Till date, numerous bioactive SMs has been isolated and characterized so far, still the Mother Nature must have many new in her basket. So, a meticulous and organized study has been needed in order to recognizing and documenting the plants that have been biologically significant and presented array of SMs of therapeutic importance. *C. citratus* (lemongrass) has been envoy species of genus *Cymbopogon* that belongs to family Poaceae. Lemongrass has been well known for its numerous conventional usages and used to cure coughs, headache, elephantiasis, gingivitis, leprosy, flu, arthritis, malaria, ophthalmic, vascular disorders, and pneumonia, etc.

The phytochemical diversity of lemongrass has chiefly been represented by flavonoids, phenolic acids, tannins, fatty alcohols, steroids, and terpenoids (mainly mono-, sesqui-, and triterpenoids) classes of SMs. These classes of SMs have been largely responsible for its numerous pharmacological activities especially its antioxidant potential. Apart from this lemongrass also have large number of health benefits as discussed above. These facts related to pharmacological and health benefits of the plants have been sufficient to support the fact that the lemongrass can be used as natural remedy for various kinds of ailments. In spite of this, still there has been need of more pharmacological justifications to explain its potential as natural remedy. The current data would be encouraging in the development of today's research in the investigation of new pharmacologically potent SMs (especially natural antioxidants) from plants belongs to genus *Cymbopogon*. Therefore, it is very crucial, to conserve our diverse natural flora and to support their protection to maintain inexhaustible sources of potent leads SMs, which may have numerous applications in various fields.

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# Pumpkin

# 5

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**Abstract**

Pumpkin fruits are increasingly considered as "functional food" endowed with important nutritional and bioactive compounds providing several health benefits. Different pumpkin fruit fractions (seeds, peels and flesh) are nutritionally balanced sources of dietary antioxidants as well as various vitamins, carotenoids, and phenolics. The intake of those compounds has beneficial effects on human health. Consumption of pumpkin is conversely correlated with the development of various diseases or their symptoms through mechanisms, including antioxidant and anti-inflammatory properties. Therefore the endeavor of this was to summarize the significance of bioactive compounds in pumpkin fruit and the related health benefit following their consumption.

**Keywords**

Pumpkin · Antioxidant properties · Anti-inflammatory properties · Health benefits

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## 5.1 Introduction

### 5.1.1 Botanical Name, Common Name

Pumpkin (*Cucurbita* spp.), which belongs to the family *Cucurbitaceae*, is a worldwide important agricultural produced and consumed all over the world. *C. pepo*, *C. maxima*, and *C. moschata* are the common worldwide produced species of pumpkin under various climatic conditions (Dhiman et al. 2009; Schaffer and Paris 2003; Ahmad and Khan 2019).

Numerous agricultural products are major sources of functional components consisting of nutrients and bioactive phytochemicals which may provide substantial health benefits and contribute to the good status of the human health. Pumpkin fruits are an extremely healthful agricultural crop with balanced mixture of beneficial nutrients for human health and nutrition (Dhiman et al. 2009; Dar et al. 2017; El Khatib and Muhieddine 2019). Recently, an increasing interest has been given not only to the pumpkin flesh but also to some of its by-products mainly seeds and peels used traditionally as medicine in many countries (Caili et al. 2007; Gutierrez 2016; Dar et al. 2017). The significant health-giving properties of pumpkin fruits might be ascribed to their high content in various phytochemicals. Here below we report the phytochemical composition of different pumpkin fruit fractions as well as the health beneficial effects related to their consumption.

### 5.1.2 History

The genus *Cucurbita* is native to the Americas several thousand years ago, but nowadays, it is widely spread throughout a large area in the world and adapted to various climatic conditions (Ahmad and Khan 2019). In fact, *C. pepo*, one of the oldest cultivated species, is originating from North America, whereas *C. maxima* is native to South America. *C. moschata* is originating from northern South America (Schaffer and Paris 2003; Gutierrez 2016; Ahmad and Khan 2019).

### 5.1.3 Production (India, World)

Pumpkin is an economically important agricultural crop with a world production of around 27.64 M. tons (FAOSTAT 2018). Presently, China is the top producer with up to 8.13 million tons of yearly production followed by India with 5.57 million tons.

### 5.1.4 Botanical Description

The pumpkin (*Cucurbita*) genus is comprised of about 20 species. *C. pepo*, *C. moschata*, and *C. maxima* are the common worldwide produced pumpkin species

(Kulczynski and Gramza-Michałowska 2019). The pumpkin cultivars possess substantial variability in the fruit traits, such us shape, size, and color of flesh. Pumpkin plants are used as ornamental and edible plants. Pumpkins (*Cucurbit* sp.) is an annual dicotyledonous plant, hispid, and scabrous, with a procumbent stem and branching tendrils characterized by trifoliate (Caili et al. 2006), large, cordate, palmately s-lobes, or angled and denticulate leaves. Pumpkin exhibits large botanical variations between species concerning leaves shape and aspects (Schaffer and Paris 2003).

Pumpkins plant is monoecious producing large yellow or orange flowers. The multilocular ovary is ovoid to elliptical, and female flowers have sturdy peduncles and a larger corolla than that of a male flower with thickened style and three lobate stigmas (Yadav et al. 2010; Schaffer and Paris 2003). The male flowers are long pedunculate and located under the leaves, at the end of the long stems, while the female flowers are at their base, the ovary. Pumpkins may be self-pollinated using their own pollen following pollinator intervention (Yadav et al. 2010).

Pumpkin fruits show a large variation in size and shape. The average weight of pumpkins fruits varies from 8 and 10 Kg and may reach over 34 kg. *C. pepo* varieties are the miniature pumpkins, whereas *C. maxima* varieties are the giant type (Dhiman et al. 2009). The skin of the pumpkin fruits is usually ribbed and orange colored although some varieties are green, gray, yellow, or red in color. For *C. pepo* L., the fruit is predominantly spherical, flattened, ovoid, and bottle shaped. The peel color varies from orange, yellow, green, white, black, or even purple. The pulp is mostly orange or yellow with seeds filled inside the berry (Marie-Magdeleine et al. 2011; Schaffer and Paris 2003).

Seed fraction represents at least 3.1% of total pumpkin fruit weight composed of (peptics) which are creamy white or a dark brown to black colored seeds, small, flat green, and edible with chewy texture and having rich nutty flavor (Karanja et al. 2013; Yadav et al. 2010). In *C. pepo*, seeds are yellowish similar to those of the *Citrullus lanatus* (Johnson et al. 2013). Most pumpkin seeds are covered by a white and firm shell; however, some varieties have huskless seeds (Dhiman et al. 2009). The seeds can be numerous ovate-elliptical and flattened (Yadav et al. 2010). Generally, pumpkin fruits can be harvested at 60 days after anthesis for obtaining seeds with maximum physiological quality and the lowest water content (Neto et al. 2015).

## 5.2 Antioxidant Properties

Antioxidant phytochemicals are attracting increasing interest for their ability to counteract free radical species reducing the risk of various human diseases. Pumpkin fruits a nutritionally balanced source of dietary antioxidants vitamins (A, C and E), carotenoids (β-carotene, lutein, zeaxanthin), and phenolic compounds (Dhiman et al. 2009; Gutierrez 2016; Dar et al. 2017; Achilonu et al. 2018; El Khatib and Muhieddine 2019) Besides the pulp, researchers are increasingly focusing on non-conventional source of phytochemicals such as pumpkin fruits by-products consisting of seeds and skin (Gutierrez 2016).

### 5.2.1 Fruits

It was reported that the nutrient compositions composition of pumpkin fruit differs considerably among pumpkin species, varieties, and fractions (Kulczynski and Gramza-Michałowska 2019; Kim et al. 2012). Pumpkin fruit is a source of several antioxidant vitamins. It has been particularly recognized as rich in vitamin C, vitamin A (in the form of carotenoids), and vitamin E (Dhiman et al. 2009; El Khatib and Muhieddine 2019).

Many authors previously assessed vitamin C content in pumpkin cultivars. Zinash et al. (2013) and Zhou et al. (2017) reported L-ascorbic acid values from 48 to 139 mg/kg fw in fresh pumpkin cultivars. Zhao et al. (2015) and Sharma and Rao (2013) reported somewhat greater levels from 144.9 to 209.8 mg/kg of fw. Similar, values ranging from 125 to 395 mg/kg fw in raw pumpkin cultivars were also reported recently by Amin et al. (2019), when assessing indigenous and hybrid varieties of pumpkin (*C. maxima*) cultivated in Bangladesh. In addition, it has been reported that vitamin C content in *C. maxima* is generally higher than *C. Pepo* and can reach very high levels attaining 500 mg/kg fw (three to fivefold higher than *C. Pepo*) (Danilchenko et al. 2000; Biesiada et al. 2011). On the basis of dry weight of pumpkin cultivars, Kulczynski and Gramza-Michałowska (2019) compared the flesh of 15 pumpkin varieties of 2 pumpkin species, the *C. pepo* and *C. moschata*, in terms of their bioactive compound content and found that vitamin C varied from 419.8 to 830.5 mg/Kg in *C. moschata varieties* and between 513.1 to 828.9 mg/Kg in *C. pepo* which suggest that different pumpkin cvs can be considered as valuable source of vitamin C.

Vitamin C is an excellent antioxidant particularly in preventing oxidative stress and recycling tocopherols and other antioxidants (Kim et al. 2012). Pumpkin fruit are known to be relatively good to excellent sources of E (tocopherols). Vitamin E (tocopherols) protects lipid from destructive oxidation, traps free radicals, and exerts a protective role against cell oxidative damage (Kim et al. 2012). It is widely recognized that α-tocopherol is the dynamic form of vitamin E, but γ-tocopherol has the greatest bioactivity (Seleim et al. 2015).

Great genotypic variation in tocopherol contents was observed in several studies. Kim et al. (2012) performed a fractionate analysis targeting tocopherol contents in the main pumpkin species and noted that α-tocopherol content in pumpkin flesh varied between 1.4 and 2.3 mg/kg fw in *C. pepo* and *C. maxima*, respectively. *C. moschata* accumulated 0.5 mg/kg fw of γ-tocopherol in the flesh. *C. maxima* accumulated interestingly greater flesh and peel α-tocopherol fractions with respect to the other species. Seleim et al. (2015) evaluating some micronutrients in three cultivars of pumpkin (*C. maxima*) found that the content of α-tocopherol in pumpkin pulp ranged from 1.67 to 15.47 mg/kg. Recently, Kulczynski and Gramza-Michałowska (2019) reported that pumpkin pulp fraction contained α- and γ-tocopherol and reported α-tocopherol levels between 17 and 64.4 mg/kg expressed in dry weight in *C. pepo* varieties and from 17.1 to 58.5 mg/kg dw in *C. moschata varieties.* They also reported that γ-tocopherol values ranged between 6.8 and 80.7 mg/kg dw in *C. pepo* varieties and between 6.5 and 74.6 mg/kg dm in *C. moschata varieties***.**

Pumpkin fruits are abundant source of pro-vitamin A carotenoids (Karanja et al. 2014). The β-carotene is known to be converted to vitamin A through cleavage and various cleavage reactions (Dhiman et al. 2009; Tanaka et al. 2012). Some particular carotenoids mainly α- and β-carotene are actively converted to vitamin A within human cells which enable retaining optimal function of eye vison, tuning of the immunity and other vital functions (Ellison et al. 2017). Seleim et al. (2015) showed that vitamin A contents ranged from 2290.9 to 5522.4 IU in the pulp of three *C. maxima* cultivars.

Pumpkin fruits are recognized to accumulate high levels of β-carotene (Seo et al. 2005; El Khatib and Muhieddine 2019). Besides, other carotenoids are also present in pumpkin such as lutein, α-carotène, and zeaxanthin (Kulczynski and Gramza-Michałowska 2019; Moreira et al. 2020).

Carotenoid content in pumpkins has been shown to be genotype-dependent. β-carotene constitutes major form of carotenoids present in orange-fleshed cultivar (Seo et al. 2005; El Khatib and Muhieddine 2019). However, lutein constitutes major form of carotenoids present in bright yellow-fleshed cultivar (Kulczynski and Gramza-Michałowska 2019). Great genotypic variability affecting total and individual carotenoid contents was observed in several studies. Previously, Biesiada et al. (2011) assessed different cultivars of pumpkin belonging to *C. maxima* and *C. pepo* for their total carotenoids content and obtained values ranging from 5.7 to 184 mg/kg fw. They also noticed that values of total carotenoids obtained in fruits of *C. maxima* over three to five times higher with respect to *C. Pepo* cultivars. Slightly higher values ranging from 236.1 to 290.6 mg/kg in raw pumpkin (*C. moschata*) cultivars were reported by Souza et al. (2012) and De Carvalho et al. (2012). In another investigation, Priori et al. (2017) evaluated 10 landraces of *C. moschata* for their total carotenoids and reported values ranging between 131 and 367 mg of β-carotene equivalent/kg fw. Similarly, Ramos et al. (2009) reported a range of 105–356 mg/kg for carotenoids among *C. maxima* accessions suggesting the importance of such material as a source of dietary carotenoids. Martínez-Valdivieso et al. (2015) noted more than tenfold differences affecting total carotenoid content (35–371 mg/kg dw) between epicarp and mesocarp of different pumpkin cvs. In addition, Kreck et al. (2006) showed that total carotenoid contents in pumpkin pulp ranged from 17 to 683 mg/kg dw, when assessing different varieties belonging to *C. maxima.*

As regard to β-carotene and lutein contents, Martínez-Valdivieso et al. (2015) noticed variations between 3.4 and 45 mg/kg dw forβ-carotene and between 32 and 333 mg/kg dw for lutein in pumpkin mesocarp with significant levels of *β*-carotene in winter squash cultivars. Additionally, Kreck et al. (2006) reported similar levels of *β*-carotene ranging from 17 to 263 mg/kg expressed in dry weight and for lutein ranging from 20 to 146 mg/kg dw in pumpkin pulp. Recently, Kulczynski and Gramza-Michałowska (2019) reported that β-carotene and lutein levels varied between 14 and 83.3 mg/kg dw and from 734 to 229.2 mg/kg dw and from 42.4 to 115.6 mg/100 g dw in *C. pepo*. However, it ranged from 12.9 to 52.6 mg/kg dw and from 42.4 to 115.6 mg/100 g dw in *C. moschata varieties.* Murkovic et al. (2002) reported variations attaining 74 mg/kg fw and 170 mg/kg fw for β-carotene and lutein, respectively, in different pumpkin genotypes. Kim et al. (2012) and Karanja et al. (2014) reported similar range for β-carotene between 1.48 and 35.09 mg/kg fw. Even though the major carotenoids in pumpkin are β-carotene and lutein, some other carotenoids have been reported such as violaxanthin and lutein in *C. moschata* (Provesi et al. 2011; Azevedo-Meleiro and Rodriguez-Amaya 2007). However, besides β-carotene, minor levels of violaxanthin and lutein have been reported in *C. maxima*. Provesi et al. (2011) noticed that all-trans-β-carotene content in raw *C. pepo* and *C. maxima* pumpkin varied between 13.38 and 19.45 mg/kg fw, respectively. However, particularly cis-isomer of β-carotene with content attaining 0.52 mg/kg fw was detected in *C. moschata* .The authors also revealed the presence of ζ-carotene and violaxanthin in minute amounts in pumpkin ranging between 0.30–4.62 mg/kg fw and 1.19–3.08 mg/kg fw, respectively. Kulczynski and Gramza-Michałowska (2019) detected the presence of three main carotenoids in different pumpkin genotypes (lutein, β-carotene and zeaxanthin). Nevertheless, other minor carotenoids might be detected at lower levels such as α-carotene, and other isomers ofβ-carotene *C. moschata* species. zeaxanthin, β-cryptoxanthin, and *α*-carotene are also present in minor levels. Jaswir et al. (2014) reported values attaining 2.2 mg/kg fw for zeaxanthin in *C. moschata*, whereas Martínez-Valdivieso et al. (2015) reported values reaching 5.8 mg/kg dw. Regarding *α* -carotene, Provesi et al. (2011) found values ranging between 0.4 and 12.6 mg/kg fw. Likewise Murkovic et al. (2002) recorded *α*-carotene values ranging between 0 and 75 mg/kg dw.

Pumpkin fruit constitutes also a significant source of phenolics (Zdunic et al. 2016; Zhou et al. 2017; Kulczynski and Gramza-Michałowska 2019). Similarly to carotenoids, the content of phenolic is mainly affected by genotypic differences. Zhou et al. (2017) assessed three pumpkin species for their total phenolic content and reported values ranging between 50.2 and 453.7 mg GAE/100 g fw, *respectively*, in *C. pepo and C. moschata*. Likewise, Zdunic et al. (2016) obtained phenolic values attaining 90.6 mg GAE/100 g fw in pumpkin pulp of *C. maxima*. In addition, a range of 26.3–80 mg chlorogenic acid equivalent/100 g fw for phenolics was reported by Priori et al. (2017) in various accessions of *C. moschata* landraces. Regarding flavonoids, Zhou et al. (2017) reported values ranging between 0.51 and 8.23 mg QE/100 g fw in *C. pepo* and *C. maxima*, *respectively*. Recently, Kulczynski and Gramza-Michałowska (2019) identified numerous flavonols in pumpkins fruits, such as rutin and kaempferol detected at high levels and considered as the major flavonols.

Besides flavonoids, some other phenolics have also been reported in pumpkin. Kulczynski and Gramza-Michałowska (2019) showed that some phenolic acids such as caffeic, gallic, 4-hydroxybenzoic, and protocatechuic acids and rutin were detected in different pumpkin cultivars at high amounts major phenolic acid, whereas vanillic acid and chlorogenic acid were detected at lower levels.

Nevertheless, *C. pepo L.* genotypes exhibited particularly higher phenolic acids with respect to *C. moschata*.

### 5.2.2 Juice

Pumpkin juice is a significant source of phytochemicals mainly carotenoids; however, a main part is lost during juicing and processing (Kreck et al. 2006). Kreck et al. (2006) showed that total carotenoid contents in pumpkin juice ranged from 3.7 to 19.7 mg/L, when assessing the juice of three *C. maxima* varieties consisting mainly of β-carotene and α- and β-cryptoxanthin. Some isomers of cryptoxanthin (α- and β-isomers) were present in Rouge juice cultivar at levels of 0.6 mg/l of each, respectively. Zdunic et al. (2016) reported that that total carotenoid and total phenolics in *C. maxima* juice reached 28.6 μg/g fw and 93 μg GAE/g fw, respectively.

### 5.2.3 Seeds

Generally, we are familiarized to consume the pumpkin fruit itself and the seeds are discarded as by-products with no commercial value. However, during the last decade, a particular focus was dedicated to pumpkin by-products such as seeds to recommend their consumption and reutilization for human consumption (Yadav et al. 2010; Ahmad and Khan 2019). Pumpkin seeds have been consequently subjected to particular attention for their content of health promoting compounds such as carotenoids and vitamins. In fact, pumpkin seeds and seed oil have a high content of vitamin E (tocopherol) with various attributed biological properties (Yadav et al. 2010; Ahmad and Khan 2019).

Pumpkin seeds represent 3.1% of total fruit weight with 33% of protein and 47% of oil (Samaha 2002). They are consumed raw or roasted and used in as bread composite flour and cakes (Gutierrez 2016). Pumpkin seeds contain a wide array of health-promoting bioactive components such as polysaccharides, mineral salts, vitamins, carotenoids as α-carotene, β-carotene, lutein, cis-lutein, lutein epoxide,α- and β-cryptoxanthin, violaxanthin, luteoxanthin, flavoxanthin, chrysanthemaxanthin, auroxanthinepimers, and others (Rabrenovic et al. 2014; Seo et al. 2005; Gutierrez 2016).

Fresh pumpkin seeds are rich in vitamin E (Kirnak et al. 2019; Salehi et al. 2019). The level of vitamin E is also affected mainly by genotypic differences. Previously, Ardabili et al. (2011) reported that vitamin E content reached 88.8 mg/100 g in *C. pepo* seeds, whereas Rezig et al. (2012) reported vitamin E values as 41.9 mg/100 g in *C. maxima* seeds. Recently, Kirnak et al. (2019) reported values ranging between 41.6 and 55.3 mg/100 g under water deficit irrigation. Nevertheless, lower values ranging from 4.5 mg/100 g to 9.3 mg/100 g were reported recently by Salehi et al. (2019). The vitamin E profile of fresh pumpkin seeds as reported by Murkovic et al. (2004) contains levels ranging from 37.5 to 383 mg/g of α- and γ-tocopherol and ranging from 16 to 128 μg/g α- and γ-tocotrienol, respectively. *C. pepo* and *C. moschata* seeds exhibited particularly higher γ-tocopherol with respect to C. maxima (Rahman et al. 2019). Phillips et al. (2005) reported γ-tocopherol values as 2.9, 6.1, and 6.6 mg/100 g in the seeds of *C. maxima*, *C. pepo*, *and C. moschata*, respectively. Recently, Salehi et al. (2019) reported higher levels of γ-tocopherol than α-tocopherol in pumpkin seeds.

*Regarding* β-carotene, it has been reported that *C. maxima* accumulate higher levels in seed fraction with respect to *C. pepo* and *C. moschata* (Rahman et al. 2019; Achilonu et al. 2018) and values vary between 7.2 to 17.5 mg/kg for *C. moschata* and *C. pepo* seeds and 31.4 mg/kg for *C. maxima* (Phillips et al. 2005).

Total phenolic in fresh and cooked pumpkin seeds can vary considerably depending on the extraction solvent, conditions, and methodology (Saavedra et al. 2015). Total phenolic of fresh seeds are higher when extracted in 100% dichloromethane (6.1 g GAE/g dw) than in water (2.39 g GAE/g dw). In methanol, *C. pepo* seeds extract exhibited total polyphenol content ranging between 82.4 and 113 mg GA/100 g (Nawirska-Olszanska et al. 2013). Gutierrez (2016) reported that pumpkin seeds methanol extract contains high amounts of phenolic compounds ranging from 5 to 11 μmol GAE. The radical scavenging activity of pumpkin seeds methanol extract depends mainly on their total phenolic content (Gutierrez 2016).

### 5.2.4 Peel

Peel constitutes almost 5–20% of the total fruit weight which is generally discarded as by-products following commercial processing which represent an environmental problem (Hamed and Mustafa 2018). Recently, a great interest is being given to different organic wastes for their content of natural antioxidant and various other nutrients (Ali 2014; De Carvalho et al. 2012; Shi et al. 2013).

Numerous studies highlighted that the antioxidant composition of pumpkin peels varies with cultivar and/or species differences. Johnson et al. (2013) recorded ascorbic acid range from 16.4 to 8.2 mg /100 g, in dried squash gourd peel. Likewise, Asif et al. (2017) reported values ascorbic acid levels reaching 19 mg/100 g in peels of *C. pepo* peels.

As for vitamin C, great genotypic variation in tocopherol contents was observed in pumpkin peels. Seleim et al. (2015) showed that the content of α-tocopherol in winter squash pumpkin peel ranged from 167.3 to 188.9 μg/100 g dw.

Kim et al. (2012) showed that α-tocopherol content in pumpkin peel varied between 4.5 and 9.6 mg/kg fw in *C. pepo* and *C. maxima,* respectively. *C. maxima* exhibited higher α-tocopherol in the peel fractions with respect to the other species. Regarding γ-tocopherol, Kim et al. (2012) reported that its particular presence in the peel fraction of *C. pepo* and *C. maxima* with range between 0.7 and 3.5 mg/kg fw, respectively.

Pumpkin peels are also an excellent source of carotenoids. In three pumpkin species, the peel fraction exhibited higher carotenoid content (5–15 folds) higher with respect to the flesh fraction (Kim et al. 2012; Martínez-Valdivieso et al. 2015). Kreck et al. (2006) showed that total carotenoid contents in pumpkin peel ranged from 12 to 1048 mg/kg dw in *C. maxima* varieties. Martínez-Valdivieso et al. (2015) reported values ranging from 68 to 4453 mg/kg dw in the epicarp of different genotypes of summer squash.

Martínez-Valdivieso et al. (2015) reported that β-carotene, lutein and zeaxanthin attained 268, 4000 and 125 mg/kg dw in the peel of different pumpkin genotypes. In another investigation, Seleim et al. (2015) showed that the content of β-carotene in winter squash pumpkin peel ranged from 145.4 to 493.1 μg/100 g dw. In addition, Kim et al. (2012) showed that β-carotene content in pumpkin peel varied between 39.5 and 123.2 mg/kg fw in *C. pepo* and *C. maxima,* respectively**.**

In another survey, Mala and Kurian (2016) showed that the total phenolic contents in pumpkin peel determined using the folin-Ciocalteu attained 5.2 mg GAE/g. However, Asif et al. (2017) showed that total phenolic content values in *C. pepo* L. attained 2.0 GAE/100 g extract. Nevertheless, Staichok et al. (2016) noted a variation in total phenolic ranging from 145.4 to 479.1 mg/L in different pumpkin peel extracts. In regard to the total flavonoid content, Asif et al. (2017) reported levels ranging between 0.6 GAE/100 g and 0.2 GAE/100 g.

### 5.2.5 Waste

There is an increasing shift toward the concentration and the extraction of health-promoting bioactive molecules such as carotenoids from fruits and vegetable by-products and processing waste (Lima et al. 2019). During various processing steps, 55–60% peels and 5–10% seeds of various fruits and vegetables are discarded which may contribute to the pollution disposal problems (Hamed and Mustafa 2018). Therefore, efforts should be deployed at this regards to benefit of valuable health-promoting compounds in fruit and vegetable by-products.

During juice processing a significant amount of phytochemicals is discarded with the pomace. The pomace extract of pumpkin is a source of carotenoids which can be used successfully integrated in various food products as novel ingredients. Kreck et al. (2006) showed that total carotenoid content in pumpkin pomace extract ranged from 11 to 34 mg/L in the juice of three *C. maxima* varieties consisting mainly of β-carotene which ranged from 5.2 to 17.6 mg/L with the presence also of α- and β-cryptoxanthin ranging from 2.6 and 1.9 mg/L, respectively.

### 5.2.6 Pumpkin-Based Products

All anatomical fractions of the pumpkin are edible, but seeds and pulp are particularly important for food processing and nutrition (Dhiman et al. 2009; Dar et al. 2017; Kulczynski and Gramza-Michałowska 2019). Following processing steps of pumpkin fruits producing juice, jam, puree, sweet wine, and other products, significant amount of valuable health-promoting compounds still remains at high levels in various final products suggesting the presence of stable isomers of carotenoids and phenolics resistant to different processing steps.

Provesi et al. (2011) showed that about 50% of carotenoids were preserved in pumpkin puree, whereas Zdunic et al. (2016) showed that about 70% of carotenoids and 85% of total phenolics were preserved following pumpkin jam production. Zdunic et al. (2016) assessed traditional pumpkin products from northern parts of Serbia prepared from *C. maxima* for total phenolic content and reported values as 93, 227.2, and 769.1 μg GAE/g fw in juice, sweet in wine, and jam, respectively. They measured also the content of total carotenoids in pumpkin juice, sweet in wine, and jam, and it amounted to 28.6, 27.6, and 63.9 μg/g fw, respectively. Seleim et al. (2015) reported that vitamin A ranged from 4992.2 to 5166. 7 IU and vitamin E 0.7 to 1.2 IU per 100 in 100 g of fresh and processed pumpkin products.

The seed fraction of pumpkin is mainly consumed as salted and roasted snacks in many Arabic countries for their high protein and oil content (Al-Khalifa 1996). It has been reported that the level of tocopherol, particularly the levels of α-tocotrienol, α-tocopherol, γ-tocopherol, and γ-tocotrienol isomers decreased following roasting, indicating a lower stability of vitamin E isomers under heat treatment (Murkovic et al. 2004). The level of phenolic in roasted seeds is strongly influenced by the extraction solvent (Saavedra et al. 2015) since higher levels were detected when using water (3.4 g GAE/g dw) than using absolute dichloromethane (1.3 g GAE/g dw).

Pumpkin oils are produced from different *Cucurbita* species in various European, African, and Asiatic countries (Fruhwirth and Hermetter 2007). They accumulate high levels of various beneficial compounds such as phytosterols (Phillips et al. 2005), vitamins, carotenoids, and tocopherols (Atkinson et al. 2019; Dar et al. 2017). Pumpkin seed-pressed oil is an evolving food product (Akin et al. 2018) generally obtained following mechanical pressing of dried pumpkin seeds at temperatures below 50 °C (Rabrenovic et al. 2014; Nederal et al. 2012). Various factors significantly affect and modulate the levels of different bioactive compounds in pumpkin seed oil such as genotypic differences, the extraction technique, the applied agricultural practices, the climatic conditions, as well as the production and storage conditions (Nawirska-Olszanska et al. 2013) In addition, the quality of processed pumpkin seed oil is largely influenced by the unsaturated fatty acid and vitamin E contents (Akin et al. 2018). The content of vitamin E is mainly influenced by post-harvest procedures (Erdinç et al. 2018) present in pumpkin seeds oil at considerable levels in the form of tocopherol and tocotrienol (Fruhwirth and Hermetter 2007). The latter are potent antioxidant and lipid stabilizers in processed products which stabilize and boost the antioxidant potentials of oils. Based on the reported above, tocopherol content and profile in vegetable oil is of great importance quality traits (Akin et al. 2018). The γ- and α-isomers are the predominant tocopherol isomers in pumpkin seed oil with levels five- to eightfold higher compared to tocotrienols (Murkovic et al. 2004). Tocopherol content is higher in pumpkin seeds oil (280 mg/kg) with respect to olive oil (125–250 mg/kg) (Bardaa et al. 2016; Rezig et al. 2012) (Jeznach et al. 2012). The content of tocopherols in pumpkin oils can be greatly influenced by different processing conditions and prices (Rabrenovic et al.

2014). In fact, total tocopherol content in pumpkin seed oil extracted using n-hexane is similar in *C. maxima* (117.5 μg/g) and *C. pepo* (117.8 μg/g). The levels of tocopherols in pumpkin seed oil from Anatolia, Turkey, exhibited considerable amount of tocopherol ranging from 943 to 97.8 mg/100 g oil (Akin et al. 2018). In *C. pepo* seed oil, the tocopherol content can range between 35.1 and 153.8 mg/100 g (Nederal et al. 2012); Stevenson et al. 2007; Akin et al. 2018; Srbinoska et al. 2012). Karanja et al. (2013) reported that α-tocopherol content ranged from 8.3 to 122.6 μg/g in cream plain and yellow orange green spots in Kenyan *Cucurbita* spp. seed oil extracted with hexane. Akin et al. (2018) reported a range of 3.7–4.4 mg/100 g oil for α-tocopherol content in oil extracted from pumpkin seed, even though Jeznach et al. (2012) results reported a range of 107–150.5 μg/g. Kulaitienė et al. (2018) reported that γ-tocopherol was a major tocopherol isomer in seed oil obtained from different pumpkin varieties. In *C. pepo* cvs harvested from four Turkish regions, Akin et al. (2018) identified β-tocopherol as the major tocopherol isomer in pressed oil seed oil with contents ranging from 83 to 86.2 mg/100 g oil, while other isomers were detected at lower levels whileα-tocotrienols reached 0.4 mg/100 g oil β-tocotrienol ranged from 0.21 to 0.8 mg/100 g oil for and γ-tocotrienol 2.7 to 3.4 mg/100 g oil. Pressed pumpkin seed oil is also a dietary source of carotenoids mainly zeaxanthin (Akin et al. 2018). Carotenoid contents and profiles in different pumpkin seed oil are influenced by genotypic differences, seed maturity stage, oil extraction process, as well as storage conditions. Total carotenoids identified by Akin et al. (2018) in cold-pressed pumpkin seed oil and reported a range of 7.0–7.6 mg/100 g oil with β-content of carotene (0.5–0.6 mg/100 g oil), lutein (0.02–0.03 mg/100 g oil), zeaxanthin (2.6–3 mg/100 g oil), and cryptoxanthin (0.4–0.5 mg/100 g oil). Andjelkovic et al. (2010) reported that total phenolic content in pumpkin seed oil ranged from 2.7 to 5.1 mg GAE/100 g. Akin et al. (2018) detected a high levels of total phenolic acids (23.1 mg/100 g oil) consisting mainly phenolic acids such as protocatechuic, caffeic, and ferulic acid. Andjelkovic et al. (2010) revealed five phenolic compounds in six *C. pepo* pumpkin seed oils consisting of various phenolic acids with the main presence of tyrosol (more than 17 mg/kg).

Based on the reported above and the presence of various health-promoting compounds, the antioxidant activity of pumpkin seed oil was evaluated by various authors and samples exhibited interesting values (Kulaitienė et al. 2018). Akin et al. (2018) reported values ranging from 26.7 to 38.9 GAE/100 g. Changes in the values of antioxidant activity in pumpkin seed oil extracted from different samples may be explained by the complex variation in the levels and profile of various samples as well as their interactions (Tuberoso et al. 2007). Nevertheless, at least 59% of the the main part of the antioxidant activity in pumpkin seed oil is attributed to phenolic compounds and 41% to the tocopherols (Fruhwirth et al. 2003).

## 5.3 Characterization of the Chemical Compound(s) Responsible for Antioxidant Proprieties

Numerous studies have shown that antioxidant phytochemicals such as vitamins, carotenoids, and phenolics prevent and alleviate chronic diseases or their symptoms through mechanisms, including antioxidant and anti-inflammatory properties (Kwon et al. 2007; Nawirska-Olszanska et al. 2013; Shi et al. 2013; Bharti et al. 2013).

### 5.3.1 Vitamins

In the human cells, α- and β-carotene are transformed to vitamin A, a compound essential for optimal functioning of various systems and organs (Dhiman et al. 2009; Ilahy et al. 2019).

Tocopherol is a crucial compounds for various physiological process (Thompson and Cooney 2019; Atkinson et al. 2019); Thompson and Cooney (2019) highlighted the importance of tocopherol in DNA protection and various other physiological processes.

Liu (2013) highlighted the importance of vitamin C in collagen integrity maintenance as well as the transmission of nervous flux. The deficiency in vitamin C has been correlated to various disorders such as reduced appetite and muscle pathologies (Gerald et al. 2017). Additionally, vitamin C is a potent ROS scavenger which imparts this compound the ability to prevent various diseases such as coronary heart diseases and age related diseases (Guiné et al. 2011). Sarkar and Buha (2008) reported that efficiency of *C. pepo* pulp extract, rich in vitamin C, in the treatment of various gastrointestinal disorders.

Several investigations have been conducted to prove that α-tocopherol, the active form of vitamin E, helps protect human cells against degenerative disorders and diseases particularly cancer and cardiovascular disease through mechanisms, including antioxidant properties, gene expression regulation, signal transduction, as well as cell function tuning (Seleim et al. 2015; Shahidi and de Camargo 2016; Gutierrez 2016). Vitamin E exerts an antioxidant activity protecting therefore various vitamins (A and C) and red blood cells. Bharti et al. (2013) indicated that tocopherol from raw pumpkin seeds prevents and alleviates diabetes through mechanisms, including antioxidant properties.

### 5.3.2 Carotenoids

Similarly to various other phytochemicals, the intake of carotenoids is inversely correlated with contracting various diseases (Amengual 2019; Dar et al. 2017). Various carotenoids are presents in different fruits and vegetables consumed by humans, but few are detected in their serum mainly (lycopene, α-carotene, β-carotene, lutein, zeaxanthin, and β-cryptoxanthin) (Mangels et al. 1993). According to Tanaka et al. (2012), β-carotene, α-carotene, lycopene, and lutein have significant anti-cancer. It has been also suggested upon various studies that the adequate intake of bioavailable carotenoids reported above is inversely correlated with contracting several degenerative diseases (Amengual 2019; Dar et al. 2017). Johnson (2002) revealed the ability of carotenoids to help enhance immune system to combat tumoric cells.

### 5.3.3 Polyphenols and Flavonoids

The interest in plant phenolics is increasing due to their potent activity to trap and neutralize free radicals which imparts beneficial effects for human health. Phenolic can combat various pathologies and diseases such as inflammation, allergies, bacteria, viruses, and cardiovascular heart diseases (Kwon et al. 2007; Pojer et al. 2013; Dar et al. 2017). Several investigations have been conducted to prove that phenolic phytochemicals of fruit help prevent and treat diabetes, hypertension, and cardiovascular disorders (Dar et al. 2017; Kwon et al. 2007).The finding of Kwon et al. (2007) indicated that pumpkin extracts rich in phenolic phytochemicals can inhibit angiotensin-converting enzyme which can also improve glycemic balance.

Among phenolics, particularly flavonoids possess the ability to combat the causal agents of various diseases (cardiovascular complications and age-related diseases) (Liu 2004). Numerous studies have confirmed the protective role of flavonoids regarding chronic diseases. The implication of flavonoids in the prevention of some types of cancer was reviewed by Guiné et al. (2011). According to Kawai et al. (2007), flavonoids exhibited an anti-histaminic activity and therefore inflammation mediated by histamine (Welton et al. 1988). Besides, flavonoids were reported to regulate the oxidative damage of LDL with also reduce the occurrence of various degenerative diseases (Pietta 2000). Recently, increasing evidences are underlying the role of flavonoids as signaling pathways modulators (Williams et al. 2004). As reviewed by Prasad et al. (2016), flavonoids are also potent to inhibit lipid peroxidation, scavenge free radical, modulate cell-signaling pathways, detoxify the cancerous substances by enzyme stimulation, and reduce the inflammation associated with the development of free radicals.

## 5.4 Health Benefits

Phytonutrients may serve as antioxidants that involve multiple bio-functions like regulation of the redox potential within a living cell, enhancing the immune response, inducing the cell apoptosis, converting β-carotene to active vitamin A, insuring DNA maintenance, and detoxifying carcinogens (Dar et al. 2017; Sardana et al. 2018).

### 5.4.1 Antioxidant Activity

Reactive oxygen species are formed during metabolism and their excessive levels are responsible for damages affecting key biological molecules as well as altering various metabolic pathways initiating consequently various disorders and diseases (Sosa et al. 2013). Therefore, interest in natural antioxidant with capacity to scavenge different radical species is growing (Ilahy et al. 2018, 2019; Tlili et al. 2011). Pumpkin fruit is considered as functional food based on various research works underlying the high levels of polyphenolic compounds in pumpkin methanolic extract (Amin et al. 2018).

In flesh, peels and seeds, *Cucurbita* species contain various nutrients essential for human health such as carotenoids and tocopherols. The β-carotene and tocopherol are mainly concentrated in peels and seed fractions, respectively (Achilonu et al. 2018). Using different analytical methods, Mala and Kurian (2016) reported similar radical scavenging activity of both pulp and peel fractions in different pumpkin cvs. The antioxidant capacity of peel and pulp fraction extracts attained 80% when using a concentration of 50 mg/ml. Due to presence of significant levels of valuable nutrients such as β-carotene, phenolics, carbohydrates, vitamins, and minerals in pumpkin fruits, various biological activities have been ascribed to their extracts against inflammations, cancers, diabetes, infectious agents, gastric complications and ulcers, bladders, as well as certain parasites such as helminthes and malaria.

### 5.4.2 Anticancer Activity

Dietary antioxidant such as phenolic compounds might control and alter evolving inflammatory pathways associated with various diseases (Sardana et al. 2018). *C. pepo* extract exhibited cytotoxic effects against the human cervical cancer HeLa cells as well as various liver and breast cell carcinoma (Gutierrez 2016; Badr et al. 2011). Similar cytotoxicity was also recorded against Ehrlich ascites carcinoma cells which were totally (100%) inhibited following exposure to an appropriate concentration of *C. maxima* extract (Abou-Elella and Mourad 2015). The anticancer activity of pumpkin extract might be exerted through mitochondrial pathway and ROS production (Da Silva et al. 2018).

### 5.4.3 Anti-inflammatory Activity

Al-Okbi et al. (2017) evaluated the anti-inflammatory activity of pumpkin seed oils and showed that administration of low and high doses of pumpkin seed oils from different origin, significantly improved various cellular markers such as DNA damages, and chromosomal damages as well as inflammation control index with respect to normal subjects. This fact might be partly explained by the lipoxygenase inhibitory activities of pumpkin seed extracts (Xanthopoulou et al. 2009).

### 5.4.4 Anti-obesity

It is widely known that extended high-caloric food intake is associated with obesity (Wang et al. 2014) which is tightly correlated to heart diseases and diabetes. The intake of natural bioactive compounds with recognized anti-obesity effect, such as pumpkin extract, is becoming an alternative for medical care targeting the control of body weight (Ghahremanloo et al. 2017). Recently, Alshammari and Balakrishnan (2019) revealed that pumpkin chloroform extract exerted significant adipogenic inhibition and downregulated various genes such as ADIPOQ, FABP4, PPARGC1A, CEBPB, and LPL while upregulating of ACACB and CEBPA genes.

### 5.4.5 Anti-diabetes

Diabetes is a metabolic deficiency which might be caused by obesity, leading to high blood sugar levels. In view of the deleterious effect of maintained high blood sugar levels, diabetes can be considered as a major concern for human life. Therefore, the use of natural extract, such as pumpkin polysaccharides, with high activity in combatting blood sugar content is of great importance. In this context, Lu et al. (2019) evaluated pumpkin polysaccharides for their anti-diabetic effect. The authors revealed that pumpkin polysaccharides might stimulate the secretion of endogenous GLP-1, decrease oxidative damages, and brake diabetes installation, are the main steps explaining the anti-diabetic mechanism of pumpkin polysaccharides. *C. maxima* seed extracts exhibited also anti-diabetic activity mainly ascribed to the presence of α-amylase and α-glucosidase (Kushawaha et al. 2017). Marbun et al. (2018) evaluated the efficiency of antidiabetic effects of pumpkin flesh and seed extracts in streptozotocin-induced mice model and concluded that pumpkin flesh and seeds ethanolic extracts at an appropriate dose triggered a considerable decrease in blood glucose.

### 5.4.6 Antimicrobial Activity

**P**umpkin fruit is rich in large-spectrum antimicrobial compounds (Muruganantham et al. 2016). Previously Asif et al. (2017) revealed that pumpkin peel and puree have a great ability to decrease and kill various infectious agents. Abdel-Rahim et al. (2018) also investigated the efficiency of different pumpkin (*C. pepo*) seed oil extracts against *A. niger* and *P. italicum* fungi and *E. coli* and *S. aureus* bacteria. In this study, pumpkin oil extracts exhibited higher inhibiting efficiency against bacteria than fungi. However, heating and volatilization significantly decrease pumpkin seed oil biological activity. Therefore, Sohail et al. (2019) suggested the encapsulation as an effective approach for protection of active ingredients of pumpkin seed oil.

### 5.4.7 Antimalarial Activity

Malaria is caused by *Plasmodium falciparum* and *Plasmodium knowlesi* which are able to induce various damages to the infected blood cells and trigger microvascular dysfunction (WHO 2014; White 2017). In this context, Mullai and Jebanesan (2007) reported that the beneficial effect of pumpkin to improve and boost immunity against malaria. Additionally, the use of pumpkin leaves was revealed effective in combatting mosquito bites causal agents of malaria.

### 5.4.8 Anthelmintic Activity

An efficient anthelmintic is being increasingly required in order to struggle helminths infection. Pumpkin seeds are since the antiquity recognized as anthelmintic (Srivastava and Singh 1967; Gupta et al. 2015). Previously, Ayaz et al. (2015) pointed out that both water and ethanol extracts of pumpkin seeds exhibited an effective anthelmintic activity with 81% and 85% inhibition respectively against *A. tetraptera* in rats. Abdel Aziz et al. (2018) reported that the anthelmintic efficiency of pumpkin seed ethanolic extract against *A. galli* adult worm was similar to fenbendazole which suggest its use as anthelmintic treatment.

### 5.4.9 Scolicidal Activity

Hydatid disease is a parasitic disease caused by *Echinococcus* spp., leading to significant complications. Therefore scolicids are being increasingly tested and characterized. It has been reported that *C. maxima* seed extract has efficient in vitro scolicidal activity against protoscolices of hydatid cyst. Babaei et al. (2018) reported that using the methanolic extract of *C. maxima* (50 mg/ml), 100% of mortality was obtained after 1 h. Which highlight the potential use of such extract as scolicidal agent due to its safety compared with used chemical drugs.

### 5.4.10 Anti-ulcer Activity

Gastrointestinal complication is an increasing problem mainly ascribed to the modern lifestyle. Herb-based preparations are also being used to treat those complications. It has been reported that various gastric pathologies such as ulcer might be successfully treated following the consumption of adequate amount of pumpkin pulp juice. In fact, in an experiment using two groups of rat, the first received an aspirin treatment, and the second treated with *C. pepo* juice highlighted the effectiveness of using pumpkin juice as anti-ulcer and gastroduodenal protective treatment (Jain et al. 2017; Sarkar and Buha 2008).

## 5.5 Conclusion

Although many people are just accustomed to consuming the flesh of pumpkin fruits, seeds and the peels are also edible parts and nutrient-rich fractions in bioactive compounds, providing considerable medicinal, health, and economic benefits if properly consumed or utilized in food products and/or as value added products. Thus, it is evident that pumpkin fruit possesses a wide range of useful medicinal properties, which can be further exploited and confirmed.

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# Tinda (*Praecitrullus fistulosus*)

6

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**Abstract**

Tinda, also known as round melon, is grown in the form of an immature fruit. It is primarily cultivated in North and Northwestern parts of the country. It is one of the most significant plants of the family Cucurbitaceae due to its medicinal properties. It contains higher amounts of phytoconstituents such as phenolic compounds, flavonoids, saponins, tannins, cardiac glycosides, and terpenoids possessing adequate antioxidative value and also acts as free radical scavengers. The fruit of tinda comprises of carbohydrates, fats, digestible proteins, vitamins, and pivotal minerals such as phosphorus, calcium, and magnesium along with various biological active metals such as Cu, Fe, Zn, Ni, Mg, Na, Cr, Cd, Pb, and Co. In addition to its antioxidant activity, it can also be used as antimicrobials, antihelminthics, and in treatment of diabetes mellitus. The partially purified lectin (PfLP) obtained from fruit juice of tinda is highly effective in reducing tumor growth by targeting angiogenesis and thus possesses antiangiogenic and antitumor properties. Thus, *P. fistulosus* can be regarded as a storehouse of natural antioxidants, which have a potential enough to act as ingredients having

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high therapeutic value, inhibiting degenerative diseases and other oxidative deterioration phenomena.

**Keywords**

Tinda · phytoconstituents · antioxidatives · antimicrobial · antihelminthics · partially purified lectin

## 6.1 Introduction

### 6.1.1 History

*Praecitrullus fistulosus*, commonly termed as tinda, is a unique, significant summer vegetable belonging to the family Cucurbitaceae. It is primarily grown in India, Pakistan, Afghanistan, East Africa, Ghana, and Kenya. The vernacular names of *P. fistulosus* include apple gourd, round gourd, and baby pumpkin (English), Dhemase (Marathi), Tandus, Tendu and Tinda (Punjab), Tindsi (Rajasthan), Dilpasand (Sind), Tinda Kaaya (Telugu), Kovaikkaai (Tamil) (Kirtikar and Basu 1998). It is a tropical plant probably originated in northwestern India, where wild species of this genus are prevalent. In Indian states such as Maharashtra, Punjab, and Rajasthan, it is cultivated and marketed as seasonal vegetable. In the other parts of the world, it is recognized with its Hindi name "tinda." In Africa, mainly in East Africa, its cultivation is done locally for the consumption of Asian masses in the vegetable form. In Ghana and Kenya, it is grown as an export product for United Kingdom (Schippers 2004). The various synonyms of different species of tinda are *Citrullus lanatus, Citrullus fistulosus*, *Praecitrullus fistulosus*, *Citrullus vulgaris* var. fistulosus, *Colocynthis Citrullus* var. fistulosus (Gautam and Shivhare 2011).

### 6.1.2 Taxonomical Classification

The taxonomy of *P. fistulosus* is in the Kingdom: Plantae; Subkingdom: Tracheobionta; Division: Magnoliophyta; Class: Magnoliopsida; Order: Cucurbitales; Family: Cucurbitaceae; Genus: Praecitrullus; Species: P. fistulosus (Tyagi et al. 2017). The plant genus *Praecitrullus* is a monoecious, climbing or trailing annual herb belonging to Cucurbitaceae family, which comprises of 90 genera along with about 700 species. The Cucurbitaceous are also characterized by the presence of supportive coiled tendrils and five angled semihard stems (Kader 2002).

The taxonomic classification of *Praecitrullus fistulosus* was studied by Levi et al. (2010). In this particular study, the genetic relationship of *Praecitrullus fistulosus* to *Citrullus species*, *Cucumis species, Benincasa hispida, Lagenaria siceraria*, and *Cucurbita species* was assessed using two DNA markers. The phylogenetic data indicated that *Benincasa hispida* resembles *Praecitrullus fistulosus* to a great extent having spherical pollen grains, which complies with the phylogenetic association between these two species.

### 6.1.3 Production (India, World)

*Praecitrullus fistulosus*, a cucurbit grown in the form of an immature fruit, is mainly cultivated in North and Northwestern parts of the country. It is also well-liked in other South Asian countries like Pakistan, Afghanistan, Sri Lanka, and Bangladesh. It is the sole member pertaining to the genus *Praecitrullus* and is cultivated as a vegetable in Punjab, Uttar Pradesh, Rajasthan, Bihar, Madhya Pradesh, Andhra Pradesh states of India. Like all other members of family Cucurbitaceae, the plant of tinda is also prolific vine and is grown annually. This unique cucurbit is very famous in Indian and Pakistani cooking with respect to many gourmet dishes. Its production in Africa is very restricted. It is mainly grown on a small scale for market. The demand is only from indigenous population of India. It is also grown sparsely in United States. There is some limited export of cultivated *P. fistulosus* from Ghana and Kenya to the United Kingdom (Schippers 2004).

The prime areas of tinda cultivation are in the lower lands from ocean level up to 1000 m altitude approximately. The growth of this vegetable is highly influenced by atmospheric conditions. It grows well in warm and sunny climate with temperature of 25–30 °C during day and 18 °C during nighttime. While in the cooled and humid climate conditions, the vegetable does not perform well. In India, it is generally grown either in dry weather from February to April and in mid-June to end of July during rains. The roots of tinda prefer sandy soils for easy penetration in depth. Fertility of the soil is necessarily required for the rapid folding of vegetation cover (Gautam et al. 2011). This vegetable plant can be grown on garden edges as well as in river beds. Cultivation of two types of tinda bearing green and pale green fruits is done (Wealth of India 1950). Harvesting is done within 13–15 weeks after sowing, depending upon temperature, humidity, and other conditions necessary for growth.

### 6.1.4 Botanical Description

*Praecitrullus fistulosus* is one of the miraculous plants of family Cucurbitaceae. It is a diffuse, monoecious, climbing, or creeping herb having stout or hairy stem. Leaves have shape similar to that of a hand with the fingers extended having five lobes. These are pinnately divided, lamina lightly covered with stiff hairs all over but heavily on the under surface. The margins have small teeth with young leaves covered with villi to heavily hispid. Stipules are absent. Probract spathulate are 0.8 cm long (Gautam et al. 2011).

The unisexual flowers are actinomorphic. The perianth has an epigynous zone carrying 3–6 lobes of calyx and 3–6 petals or 3–6 lobed sympetalous corollas. The androecium is extremely variable, composed of five typically distinct to entirely connate stamens, which are normally twisted, folded, or fewer in number (Akwaowo et al. 2000).

The gynoecium of the plant consists of individual compound pistil comprising of 2–5 carpels, usually having one style. Pistil also comprises of several style branches and an inferior ovary having one locule along with abundant ovules on 2–5 parietal placentae. The fruit is a type of berry termed as pepo by Gerald Carr. It is spherical, firm, slightly flattened in shape and 5–8 cm in diameter. It contains numerous seeds and appears to be pale to dark green from outside and creamy whitish to pale greenish in color from inside. The seeds are flattened, ovate-oblong in outline, about 8 mm long, smooth with ridged margin, and black in color (Akwaowo et al. 2000; Gautam et al. 2011).

## 6.2 Antioxidant Properties of Pulp, Seeds, Fruit, Leaves, and Peels

One of the necessities for healthy life is to have sufficient amounts of antioxidants in the body for neutralizing the damage caused by free radicals. The free radical species are continuously liberated in human body owing to their pivotal role in various biochemical processes. The excess production of these highly reactive substances due to either external oxidant or a failure in body defense mechanism may enhance the risk of disease. In fact, natural production of antioxidants in the body gets reduced with time and age, so it becomes essential to include antioxidant-rich food stuffs in diet. Literature studies revealed that plant materials are blessed with compounds having high antioxidant activities and are regarded as best source of potentially safer natural antioxidants. Most of these antioxidants are polyphenolic compounds. A wide range of both low- and high-molecular-weight natural polyphenols having antioxidant characteristics has been analyzed and recommended for safety against lipid oxidation (Parr and Bolwell 2000).

Natural antioxidants are thought to be more beneficial than synthetic antioxidants as synthetic antioxidants have been shown to have adverse effects in body (Stanković 2011; Pal et al. 2011). Therefore, much attention is paid toward the consumption of natural antioxidants. The major sources of antioxidants are primary and secondary metabolites, which may exist in various parts of plants such as roots, seeds, leaves, nuts, fruits, vegetables, and bark (Pratt and Hudson 1990). There are numerous bioactive agents in plants extracts that exhibit antimicrobial, antioxidant, antifungal, anticancer, and anti-inflammatory activities to a larger or smaller extent (Patwardhan 2005; Rad et al. 2014).

In regards to ever-increasing attention toward consumption of food-based antioxidants, comprehensive investigations are being conducted to estimate the antioxidant potential of commonly edible cucurbits (Tapkir et al. 2013). Among all the members of family Cucurbitaceae, *Praecitrullus fistulosus* is acknowledged as nature gifted plant having entire range of essential constituents required for well-being and better health. It has been utilized as traditional medicine for curing heart diseases, stroke, cancer, maintaining blood pressure, etc. The seeds of tinda are used as fodder and also in large number of medicines for curing various disorders (Chadha and Lal 1993). The cotyledons are utilized in vegetables in cooked form and are recognized to regulate blood pressure (Sultana et al. 2006).

Bollavarapu et al. (2016) evaluated the tinda fruit extracts for bioactive phytochemical constituents as well as for antioxidative value, reducing power, and free-radical-scavenging potential. They reported the presence of higher amounts of phytochemicals like flavonoids, phenolic compounds, tannins, cardiac glycosides, terpenoids and also concluded that all organic solvents extracts such as chloroform, ethyl acetate, hexane, and aqueous exhibit significant antioxidant and free-radical-scavenging activities.

The literature studies revealed that pulp and seeds of cucurbits have also antioxidant potential. In this context, Tapkir et al. (2013) analyzed pulp and seeds of 10 different edible cucurbits, namely, *Cucumis sativus L., Cucurbita maxima Duch., Lagenaria sinceraria Mol., Momordica charantia L., Coccinia grandis L., Luffa acutangula L., Luffa cylindrical L., Trichosanthes anguina L., Trichosanthes nervifolia L., Praecitrullus fistulosus L.* and compared all in terms of total phenolic content, total flavonoid content, $Fe^{2+}$ chelation assay, and reducing power. They presented that pulp exhibits higher antioxidant activity in comparison to seeds and also stated that cucurbits are potential supplier of antioxidants. The antioxidant potential of plant is one of the characteristic for their use as nutraceuticals (Ene-Ojo Atawodi and Onaolapo 2010; Al-Shaheen et al. 2013).

The presence of tannins, cardiac glycosides, terpenoids, saponins, and resins as phytoconstituents in *Praecitrullus fistulosus* was also reported by Sood et al. (2012). These bioactive components possess various biological roles. Cardiac glycoside has been documented to show anti-inflammatory properties (Shah et al. 2011). Saponins exhibit antitumor activities, thus reducing the risk of cancer (Nafiu et al. 2011). Tannins have capability to accelerate the curing of wounds (Njoku and Obi 2009).

Phytochemical screening and antimicrobial assay of various seeds extracts of some of the commonly available plants belonging to family Cucurbitaceae such as *Momordica charantia (Karela), Cucumis sativa (Cucumber), Praecitrullus fistulosus (Tinda), Cucurbita pepo (Kaddu), Lagenaria siceraria (Loki)* was evaluated by Sood et al. (2012). Findings of the study demonstrated that all plant seeds contain considerable amounts of phytochemicals such as terpenoids, saponins, cardiac glycosides, tannins, resins, and phytosterols and, thus, can be incorporated in various medicines for treatment of various diseases such as cancer, chronic cardiac failure, lowered blood cholesterol levels, wounds healing, etc. Results of antimicrobial assay presented that all the solvent-extracted seeds inhibit the activity of *Serratia marcescens, E. coli, Streptococcus thermophilous, Fusarium oxysporium, and Trichoderma reesei*. This antibacterial activity might be due to the presence of various phytochemicals (Egwaikhide et al. 2010). The antimicrobial potency of plants such as *Praecitrullus fistulosus* (Tinda), *Cucurbita pepo* (Kaddu) *and Lagenaria siceraria* (Loki) may be helpful to discover a new class of antibiotics that could be treated as specific agents for various infectious diseases.

The varying degree of antioxidant activity in methanolic and petroleum ether fruit extracts of tinda was assessed using standard DPPH method by Gautam and

Shivhare 2011. It was observed methanolic extracts of fruit possess higher antioxidant activity (20 μg/ml) than petroleum ether extracts (18 μg/ml).

Mutagenesis or mutation breeding is a widely used method for improving crop yield, development of new varieties, and disease resistance, and is also employed in floriculture and horticulture (Ali et al. 2007; Mensah and Obadoni 2007; Suzuki et al. 2008). The approach of induced mutagenesis was employed on *Praecitrullus fistulosus* by Khan (2015). In this study, an attempt was done to assess as well as to enhance the biochemical profile of tinda after treating the plant leaves with different physical (UV and x-rays) and chemical mutagens (colchicine and ethidium bromide). The outcome of the study presented that total carbohydrates, total proteins, phenolics, reducing capability, ascorbic acid content, antioxidant activity, and leaf pigment (chlorophyll A) were raised appreciably in the colchicine-treated (0.02%) plant leaves. Similarly, a significant enhancement was also observed in contents of flavonoids, flavonol, carotenoids, and chlorophyll B and in the ethidium-bromide-treated (0.05%) plants in comparison to control plants.

Vegetables and some fruits produced about 25–30% of nonconsumable waste products (Ajila et al. 2010). The failure to retrieve and reuse of such materials leads to generation of unnecessary waste and exhaustion of natural assets (Bhalerao et al. 1989). The whole tissue of vegetables and fruits contained ample amounts of bioactive components such as phenolic substances, carotenoids, flavonoids, anthocyanins, and, in many cases, the waste by-products can show either similar or sometimes higher concentrations of antioxidants and antimicrobial components (Ayala-Zavala et al. 2004).

The waste materials such as peels produced from vegetables and fruits can be successfully utilized as a source of phytochemicals and antioxidants. In the study of Dixit and Kar (2010), significant amounts of polyphenols, flavonoids, and ascorbic acid have been reported in the three vegetable peels from the plants: *Cucurbita pepo, Cucumis sativus,* and *Praecitrullus fistulosus* of family Cucurbitaceae.

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

Many researchers have shown interest in evaluating the plants of Cucurbitaceae family due to their medicinal and pharmacological significance. In the category of various medicinally important plants, tinda is an outstanding plant containing all vital nutrients required for well-being (Kirtikar and Basu 1998). *P. fistulosus* comprises of substantial amounts of carbohydrates, proteins, fats, fiber and also various essential metals like nickel, zinc, lead, copper, cobalt, cadmium, chromium, iron, calcium, and sodium that exhibit different biological roles (Holland et al. 1991; Hussain et al. 2010. The different parts of the plant such as fruit, pulp, seeds, leaves, and peels were examined by several researchers for their potential antioxidant properties using different methods. It was well documented that *P. fistulosus* could serve as free radical scavenger or inhibitor and also a source of natural antioxidants that could have great importance as therapeutic agents in preventing or reducing the progressive aging and age-associated oxidative-stress-related degenerative diseases. This consistency may be due to the presence of phenolic compounds as strong antioxidants (Bollavarapu et al. 2016).

Phenolic substances are the secondary metabolites in plants belonging to a heterogeneous group of chemical compounds that contains one or many aromatic rings along with one or many hydroxyl group in their basic structural formulation (Balasundram et al. 2006). These compounds are recognized for their diverse biological activities (Popa et al. 2008; Ignat et al. 2011). These are also responsible characteristics and contribute to the nutritional quality of fruits and vegetables (Lapornik et al. 2005). They tend to furnish an electron or a hydrogen atom to a free radical and convert it into an innocuous molecule. Therefore, phenolics exhibit relevant antioxidant activities. The different classes of phenolics include flavonoids, tannins, stilbenes, phenolic acids, and lignans (Hollman and Katan 1999; Robbins 2003).

Flavonoids, another group of natural substances having a benzo-γ-pyrone structure, are also recognized in *Praecitrullus fistulosus*. Numerous studies have reported that antioxidant potential of this genus might be due to the occurrence of significant amounts of flavonoids. These hydroxylated phenolic compounds are identified to be synthesized by plants for performing various pharmacological activities as well as in reaction to microbial infection (Dixon et al. 1983). The various activities performed by flavonoids are reported to be highly structural dependent. The chemical properties of these compounds depend on their structure, class, extent of hydroxylation, conjugation, nature of substituents, and degree of polymerization (Heim et al. 2002). The possible health benefits emerging from antioxidant nature of flavonoids have attracted the considerable attention in recent years. The mechanism of antioxidant activity of flavonoids may involve either scavenging free radicals and/or by chelating metal ions by hydroxyl functional groups (Kumar et al. 2013a; Kumar and Pandey 2013). The chelation of metal ions might inhibit the radical generation, which causes tissue damage (Leopoldini et al. 2006; Kumar et al. 2013b). In the research findings of Cakir et al. (2003), a linear correlation between flavonoids and antioxidant activity was demonstrated.

Flavonoids are also highlighted for their protective nature against various microbial infections. Many researchers have evaluated the antimicrobial potential of *Praecitrullus fistulosus*, which might be attributed to the presence of flavonoids. Regarding the biological properties of flavonoids, Kumar and Pandey (2013) reviewed that antibacterial flavonoids such as apigenin, galangin, flavones, flavonol glycosides, isoflavones, flavanones, and chalcones might have multiple cellular targets rather than one specific site of action. These phenolic substances are having the property to bind with proteins to form complex through nonbonding interactions such as hydrogen bonding and hydrophobic interactions as well as through covalent bonds. Thus, the mode of antimicrobial action of flavonoids may be associated with their capability to deactivate microbial adhesions, enzymes, cells envelop transport proteins (Cowan 1999; Mishra et al. 2009).

Like chemical antioxidants, the damage of tissue can also be protected against oxidative stress by enzymatic antioxidants (Halliwell and Gutteridge 2000). The enzymatic antioxidants, for instance, superoxide dismutase (SOD), catalase (CAT), and glutathione S-transferases (GST), were assessed in *P. fistulosus* fruit extracts in the significant study of Bollavarapu et al. (2016). The mechanism of action of enzymatic antioxidants may involve the interaction of superoxide dismutase (SOD) antioxidant enzyme with oxy radicals resulting in conversion of superoxide ion to hydrogen peroxide ($H_2O_2$). Catalase (CAT), a peroxisomal heme protein, scavenges hydrogen peroxide and catalyzes its disproportion into water and oxygen. Both these enzymes work mutually in order to provide protection against reactive oxygen species (ROS) (Purushothaman et al. 2012). Superoxide dismutase (SOD) and catalase (CAT) activities at 100 mg/ml in *P. fistulosus* fruit extracts were reported to be $25.27 \pm 0.42$ U/mg protein and $2359.47 \pm 0.44$ U/ml, respectively. Glutathione S-transferases (GSTs), being multifunctional proteins, participated in various intracellular events such as stress metabolism, primary and secondary metabolism, herbicide detoxification, and protection of plant against ozone damage (Mohsenzadeh et al. 2011). GST activity at 100 mg/ml in *P. fistulosus* fruit extracts was observed to be $2433.46 \pm 0.47$ n moles of CDNB conjugated/minute.

There are various methods available in literature to estimate the antioxidant activity of any plant material. The studies related to antioxidant potential of *P. fistulosus* revealed that methods like DPPH, hydroxyl-radical-scavenging assay, ferric reducing antioxidant power (FRAP), and reducing power assay can effectively evaluate the antioxidant activities.

In biological systems, the hydroxyl radical is considered to be the most highly reactive and damaging species. It seems to be responsible for producing detrimental effects in the living cell, which in turn causes severe damage to the lipids and proteins. Since phenolic compounds are good electron donors, they may accelerate the conversion of hydrogen peroxide to water molecule. In the study of Bollavarapu et al. (2016), it was reported that solvent extracts of *P. fistulosus* exhibit significant hydroxyl-radical-scavenging activity.

Ferric reducing antioxidant power (FRAP) is referred as uncomplicated assay of expressing antioxidant activity. This method determines the reducing power of an antioxidant substance reacting with a ferric ($Fe^{3+}$) tripyridyltriazine complex and producing a colored ferrous ($Fe^{2+}$) tripyridyltriazine complex (Benzie and Strain 1996). The reducing properties are mainly due to those constituents, which are capable of breaking free radical chain reaction by furnishing a hydrogen atom. In the FRAP assay, antioxidants present in the sample are considered as a reductant molecule in a colorimetric redox reaction. Bollavarapu et al. (2016) reported that the absorbance of *P. fistulosus* was clearly enhanced due to the formation of ferrous ($Fe^{2+}$) tripyridyltriazine complex. The maximum ferric reducing capacity was observed in chloroform extracts of the plant.

The reduction of $Fe^{3+}$ indicates the donation of electron, which is a significant mode of action of phenolic antioxidants. In the reducing power assay, the antioxidants in the samples donate an electron and lead to reduction of ferric ions to ferrous ions. Further, the formation of ferrous complex can be monitored by recording the absorbance of sample at 700 nm (Oyaizu 1986). Higher absorbance is directly related to the reducing ability and thus antioxidant activity. Literature reports demonstrates that fruit extracts of *P. fistulosus* show good reducing power and hence possess significant antioxidant activity.

## 6.4 Health Benefits

As per literature studies, *Praecitrullus fistulosus* has been placed among the various medicinal plants due to the presence of significant amounts of polyphenols, flavonoids, ascorbic acid, tannins, alkaloids, saponins, phytosterols, diterpenes, thiamin, carotenes, proteins, carbohydrates, and cardiac glycosides. It is cultivated and consumed comprehensively in vegetable form mainly in subtropical countries. The tinda fruit is consumed in many ways such as in cooked vegetables, pickles, or in candies.

The nutritive value of tinda is very high, comprising of carbohydrates, fats, digestible proteins, vitamins, pivotal minerals such as calcium (Ca), phosphorus (P), and magnesium (Mg), and essential trace elements including biological active metals such as Cu, Fe, Zn, Ni, Mg, Na, Cr, Cd, Pb, and Co (Holland et al. 1991; Hussain et al. 2010) (Table 6.1). Seeds and kernel parts of tinda are known to have 52.8% and 37.8% of fatty oil, respectively. The different fatty acids contained within the oil include stearic (10.70%), myristic (1.74%), palmitic (11.85%), linoleic (50.80%), and oleic (21.23%). About 60–70% protein has been found in oil-free kernel (The Wealth of India 2004).

Globulins, the salt soluble proteins, contained in seeds of tinda were reported to vary from 56.6% to 67.0%. These proteins were followed by 16.6–20.8% of albumins, 13.5–18.5% of glutelins, and 2.2–4.1% of prolamins (Gautam and Shivhare 2011). The nutritional composition of *Praecitrullus fistulosus* can be helpful to determine the various health benefits acquired from its use in marginal communities.

Among the common metabolic disorders, diabetes mellitus is characterized by loss of glucose, homeostasis, imbalance of carbohydrate, fat and protein metabolism due to defects in insulin secretion, insulin action, or both (Imam 2012). In this disorder, hyperglycemia produces reactive oxygen species (ROS), which leads to oxidative degradation of lipids and resulting in other complications such as eye, blood vessel, kidney, and nerve damage. Literature studies showed that antioxidants inhibit the propagation of peroxidation chain reaction and thus avert the destruction of beta cells and ultimately provide safety against diabetes (Rajaram 2013). In spite of generous advancement in treatment of diabetes by oral hypoglycemic agents, investigations for newer medicines proceed in light of the fact that the current synthetic drugs have a few constraints and destructive impacts. Natural drugs have ever been utilized and asserted as antidiabetic agents yet exceptionally less are accessible on economically figured structures (Ghazanfar et al. 2014).

Several researchers have paid their consideration towards the family Cucurbitaceae as the plants of the family are recognized to be involved into

**Table 6.1** Nutritional value of tinda fruit (per 100 g fresh weight basis)

| Nutrient | Value |
|---|---|
| Energy | 21 kcal |
| Water | 93.5 gm |
| Protein | 1.4 gm |
| Carbohydrates | 3.6 gm |
| Dietary fiber | 1.6 gm |
| Fat | 0.2 gm |
| Carotene | 13 μg |
| Ascorbic acid | 18 mg |
| Thiamine (Vit. B1) | 0.04 mg |
| Riboflavin (Vit. B2) | 0.08 mg |
| Niacin (Vit. B3) | 0.3 mg |
| Calcium | 25.0 mg |
| Phosphorous | 24.0 mg |
| Iron | 0.9 mg |
| Copper | 11 ppm |
| Zinc | 34 ppm |
| Magnesium | 33.0 mg |
| Sodium | 4 ppm |
| Nickel | <0.006 ppm |
| Lead | <0.015 ppm |
| Cobalt | <0.009 ppm |
| Cadmium | <0.0008 ppm |
| Chromium | <0.003 ppm |

Source: Holland et al. (1991); Hussain et al. (2010)

numerous Ayurvedic preparations. Karandikar et al. (2014) evaluated the antioxidant and antidiabetic potential of *Praecitrullus fistulosus* fruits in streptozotocin (STZ) induced diabetic rats. The phytochemical screening of fruit extracts revealed the occurrence of flavonoids, alkaloids, tannins, saponins, phytosterol, and diterpenes. The impact of oral ingestion of tinda fruit extract (300 mg/Kg body weight) on biochemical attributes such as blood glucose levels, urea, glycosylated hemoglobin, proteins, urine sugar, uric acid, alanine transaminase, alkaline phosphatase, and aspartate transaminase was quantified. It was demonstrated that the distorted levels of biochemical parameters were appreciably restored back to near-basal values in the diabetic rats on treatment with fruit extract. The antioxidants status was also improved. The glycogen levels were also maintained due to normalization of glycogen-metabolizing enzyme activities after treatment with fruit extracts. The improvement in antioxidant proficiency of the pancreatic tissues confirms the antioxidant potential of fruit extract. The normalization of all the parameters indicates the occurrence of various biological active secondary metabolites. The similarity in results as reported for gliclazide, an oral standard hypoglycemic drug, may indicate the antidiabetic and antioxidant property of the tinda fruit.

The partially purified lectin obtained from *Praecitrullus fistulosus* (PfLP) fruit juice exhibits promising cytotoxic effect against tumor progression. In the study of Shivamadhu et al. (2017), the antiangiogenic and antitumor effects of PfLP against Ehrlich ascites carcinoma (EAC)-bearing mice were examined in vivo. It was observed that addition of PfLP resulted in inhibition of tumor growth and also the life span of the EAC-bearing mice got enhanced without any harmful effects. Similarly, a considerable reduction in secretion levels of vascular endothelial growth factor (VEGF), which is identified as stimulating factor for tumor angiogenesis, was observed. This research study clearly demonstrates that PfLP is highly effective in reducing tumor growth by targeting angiogenesis and thus possesses antiangiogenic and antitumor properties.

Helminthic infection is one of health issues that affect human population as well as livestock in the world. The various helminths infecting the gastrointestinal systems are cestodes, nematodes, and trematodes. The existing synthetic drugs are reported to have side effects and moreover, the resisting power of these parasites is going to be increasing day by day (Kappagoda et al. 2011). Due to lesser availability and affordability of modern synthetic drugs, most of the population depends on traditional medical remedies (Rajeswari 2014; Veerakumari 2015) Literature surveys showed that most of the plants belonging to Cucurbitaceae family possess antihelminthic activity and can contribute their remedial properties against antibacterial, antifungal, and antiparasitic infections.

The antihelminthic activity of *Praecitrullus fistulosus* against *Pheretima posthuma* was investigated by Gautam et al. (2011). In their study, two concentrations (50 and 100 mg/ml) of petroleum ether and methanolic extracts were tested. The paralysis time and death time of the worms were determined using distilled water as control and Albendazole as standard. They demonstrated that the both solvent extracts of *P. fistulosus* express considerable antihelminthic activity at higher concentrations of 100 mg/ml.

In accordance with available literature, *Praecitrullus fistulosus* (tinda) has been widely used as antimicrobial, antihelminthic, antioxidant and in treatment of diabetes mellitus. It can also be employed for other health issues such as gastric problems, dyspepsia, weakness, colic in stomach, and controlling blood pressure. Besides this, globulin protein present in seeds of tinda promotes the transport of nutrients across the body and thus, it improves the overall circulation. However, the research work concerning the medicative properties of the plant is scanty and needs to be investigated.

## 6.5 Conclusion

*Praecitrullus fistulosus* or tinda is acknowledged as nature gifted plant containing all the vital constituents mandatory for well-being and better health. It is mainly cultivated and consumed in vegetable form in tropical or subtropical areas. The different plant parts such as fruit, pulp, seeds, peel, and leave exhibit significant antioxidative values owing to the existence of appreciable amounts of polyphenols, flavonoids, ascorbic acid, tannins, alkaloids, saponins, phytosterols, diterpenes, thiamin, carotenes, proteins, carbohydrates, and cardiac glycosides. Thus, *P. fistulosus* can be regarded as a storehouse of natural antioxidants, which have the potential enough to act as ingredients having high therapeutic value, inhibiting degenerative diseases and other oxidative deterioration phenomena.

In addition to this, tinda plant also possesses antihelminthic activity and can contribute their remedial properties against antibacterial, antifungal, and antiparasitic infections. Besides this, globulin protein present in seeds of tinda promotes the transport of nutrients across the body and thus improves overall circulation.

The above-presented information regarding the *P. fistulosus* is all about its botanical, phytochemicals, and pharmacological activities. Further research work is required to carry out to explore the hidden areas and their practical clinical applications that can be used for the benefit of the mankind.

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# Turnip

# 7

Mohd Aaqib Sheikh, Nadira Anjum, Amir Gull, and Charanjiv Singh Saini

**Abstract**

Turnips are considered essential for well-balanced diets since they supply vitamins, minerals, dietary fiber, and phytochemicals. They are ingested progressively as a prime source of needful nutrients by humans and constitute an important crop globally. They are attractive for consumers not only for the nutritional value, but they contain a unique combination and amount of phytochemicals, which stimulateinterest in maximizing their cultivation. Turnips are rich in vitamins, fibres, minerals as well as gainful to human welfare due to their potential jobs in the counteraction of degenerative maladies byensuring protection against free extreme harm. The major volatile compounds and the main distinctive constituents (bioactive compounds) of turnips showing medicinal properties include glycosinolates, isothiocyanates, flavonoids, indoles, sulfur compounds, phenolics, carbohydrates and volatiles (terpenes, esters, aldehydes, and ketones), nitrates, alcohols, indoles, lignans, aldehydes, sesquiterpene, phenylpropanoids, phenylglycosides, sulfurous compounds, carbohydrate derivatives, etc. Therefore, regular consumption of turnips has undeniable positive effects on health since phyto-nutraceuticals of turnips can protect the human body from different types of diseases.

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**Keywords**

Turnip · Phytochemicals · Antioxidants · Health benefits · Medicinal properties

## 7.1 Introduction

**Botanical name:** *Brassica rapa*
**Common name:** Salgam, shalgam, shaljam

Turnip (*Brassica rapa* var. *rapa*) is a popular herbaceous plant grown worldwide. It is indigenous to Europe, Asia, America, and Russia and is now extensively developed as vegetable and oil source far and wide (Paul et al. 2019). It is a very old crop species exhibiting enormous morpho-diversity and occupying wide distribution throughout the world. Brassica is the most important genus of the *Brassicaceae ancestry*, a vast family of greens and vegetables that include various cultivated plants and wild species with extensively distinguished morphological attributes (kale, cabbage, broccoli, cauliflower, Brussels sprouts) (Martinez et al. 2010). The *Brassicaceae* family is known to contain an ample quantity of phytochemicals and organic acids, which exhibit strong aroma and antioxidant property (Haliloglu et al. 2012). Turnip is consumed progressively as a prime source of needful nutrients by humans and constitutes an important crop globally (Bjorkman et al. 2011). Many species of this genus are grown for their greens, but most are grown commercially for market sale of the enlarged fleshy root because they are quite appreciated for the highly nutritive, dietetic, and against cancer-causing properties (Martinez et al. 2013). Turnip is an essential produce with nourishing and medicinal values. The main distinctive constituents (bioactive compounds) showing medicinal properties include glycosinolates, isothiocyanates, flavonoids, indoles, sulfur compounds, phenolics, carbohydrates, and volatiles (terpenes, esters, aldehydes, and ketones) (Ullah et al. 2014). Moreover, the medicinal properties of *Brassica rapa* have been well noted in the literature, for example, an ancestral therapeutic treatment for kidney and liver diseases (Gairola et al. 2014).

Turnip is an economically the most important and widely cultivated for its enlarged fleshy roots, tender growing tops, forage and oilseeds in the temperate ambience of the planet and have witnessed a constant ascending development throughout the preceding few decades (Stefanski et al. 2013). It is usually cultivated either early in the spring or as a winter crop and is characterized by the primary roots that grow vertically downward give off small lateral roots. Botanically this root is a swollen stem which develops underneath the soil from the base of the plant to anchor the plant, absorb water, nutrient, store energy and serve specific functions for the plant (Moore et al. 2007). It is an erect cool-season biennial or an annual crop that produces an excess of energy one year so that the succeeding spring, it can invest energy into blooming early. During the second year, if left in the ground produce flowers, set seed and completes the life cycle (Paul et al. 2019). Turnips are bulbous in shape and are often a mixture of the colors purple, white, and/or yellow. The bulbous white-fleshed root develops at the base of theleaf petioles, differs in size, normally 3 to 4 inches wide and 6 to 8 inches in length as shown in Fig. 1. The top 2–3 inches above the ground is an expansion of the hypocotyls that is fused with the expanded root below the ground. Leaves develop legitimately from the hypocotyl and are delineated by a peculiar bitter and pungent taste (Jones and Sanders 2002).

During the initial stages of growth, 8–12 erect leaves are produced from each plant. The leaf size ranges from 12 to 14 inches in length and 3–5 inches wide and may be harvested and eaten as turnip greens. Turnip is widely recognized for its fresh green tops with cleaved tough leaves of typically light green shading and flimsy and inadequately pubescent (bristly) surface with scalloped edges (Pierre et al. 2011). Turnip is a highly nutritious feedstuff crop due to highly digestible nutrients and crude proteins (Martinez et al. 2010). Turnip has a short growing season and can provide late fall grazing after other forage crops (feedstuff that animals search and consume) are finished for the year. Little, delicate assortments of turnip are normally developed for human utilization, while bigger woody ones are developed as feed for domesticated animals. They may be grown throughout the growing season and may also be stored for short periods depending on the availability of markets. They are harvested in the fall and available throughout the winter and spring season. They are well adapted to cool and humid conditions with an optimum germination temperature range of 15–29 °C. The best-quality turnips are successfully grown commercially as an annual in the northern plains and hilly tracts of India and are an important component of the diets of people living in the region (Padilla et al. 2005). They are well adapted for growth on a wide scope of soils but grow good in a well-drained, well-structured, reasonably profound topsoil and rich and somewhat acid soil.

The average yields of turnips could range between 25,000 and 35,000 kg per hectare (Podsedek 2007). Turnip varieties are selected based on root size and the quality. Turnips are classified into two groups, namely, white-fleshed and yellow-fleshed varieties. Most cultivars are white-fleshed except for the exposed above-ground portion and are cultivated as a vegetable crop for small tender roots and vigorous leaf production. The turnip roots of different varieties vary widely in shape, size, and color. Some common varieties include the Purple Top Strap Leaf, the Gold Ball, the Purple Top White Globe, the Purple Top Milan, the Goose Egg, the Orange Jelly, the Seven Top and the Shogun, which are both grown for their edible foliage (Ferreres et al. 2006). Some normal assortments incorporate the Purple Top Strap Leaf, the Gold Ball, the Purple Top White Globe, the Purple Top Milan, the Goose Egg, the Orange Jelly, the Seven Top, the Shogun, etc. There are many varieties of turnips; each has napiform type of roots with different flavor and storage capacity (Sun 2015). Turnip roots for edible purposes weigh around 500–1000 g, but the weight may vary with growing conditions and variety. The turnip seeds from both annual and biennial varieties are usually dark reddish color with round shape, and the weight of thousand seeds ranges from 1.6 ± 0.026 grams.

### 7.1.1 History

Turnip (*Brassica rapa*) has assumed an extraordinary job in mankind's history by contributing a decent portion of nourishment in the form of vegetables, oilseeds, forage, green manure, and condiments. The domestication of the turnip crop has varied ancient origins and is believed to have been cultivated almost 4000 years ago for its enlarged root by prehistoric man in Northeastern Europe or western Siberia or middle and central Asia (Liang et al. 2006). There is a lot of botanical, historical, and linguistic evidence that the use of this crop is very old. It is difficult to trace its origins to an exact location, but it is thought that turnip is native to the Mediterranean, from where it spreads toward Central Europe and Asia, eastward to Germany and northward to Nordic countries (Sweden, Denmark, and Norway), though counter-evidence exists. It is the most established *Brassica rapa* crop on record and was portrayed in antiquated Greek occasions of Alexander the Great. The Greek Theophrastus called it gongylis (371–285 B.C.). The oldest excavated turnip is from Greece, and Celtic tribes introduced the turnip crops in Portugal where the diversification of this crop is well demonstrated. It was probably domesticated directly from its progenitor, the wild type *Brassica rapa*. Leafy vegetables are thought to have been developed plant after they reached China via Mongolia as an agricultural crop. The turnip was a prominent tamed crop in Europe and has been eaten as a vegetable since prehistoric times for human and livestock consumption. Turnips are thought to have been adopted into the food cultures of American and African cuisines because of the crucial role they played during the days of slavery. They are grown throughout the temperate zone and have been a prominent livestock fodder for at least 600 years where grown extensively. In the middle ages, the turnip was a staple food crop and has been grown as forage since the earlier part of the twentieth century (Barnes et al. 1995). Turnip crop has been a popular livestock fodder for at least 600 years and produces high-quality forage if harvested before heading. In the late 1970showever, researchers began to demonstrate the potential health benefits of turnip and reported that turnip (*Brassica rapa*. l) is a valuable energy source. Due to the development of varieties by researchers and the corresponding high levels of variability in physical characteristics of turnips like shape, size, colour and taste, constitute a high diversity for breeding purposes as well as rendered the turnip roots more available to grazing animals (Boswell 2000). At present, *Brassica* crops hold a dominant position in the world's agrarian economy.

### 7.1.2 Chemical Composition

The nutritional value of turnips for humans can be summarized as low in fat and calories, but an excellent source of minerals, vitamins, bioactive compounds and high dry matter digestibility essential for the healthy life. The high dietetic values of turnip are derived from the rich chemical composition of the plant shown in Table 7.1. Besides being an important vegetable, turnip contains a significant amount of phytochemicals, aromatic compounds, organic acids, essential oils and

**Table 7.1** Nutritional composition of turnip plant (value/100 g)

| Parameter | Turnip root | Turnip leaves |
|---|---|---|
| Energy (Kcal) | 28.12 | 21 |
| Water (g) | 91.28 | 93.13 |
| Crude protein (g) | 0.90 | 2.46 |
| Crude fat (g) | 0.10 | 0.19 |
| Carbohydrate (g) | 6.43 | 3.39 |
| Crude fiber (g) | 1.8 | 2.4 |
| P (μg) | 27 | 24 |
| K(μg) | 191 | 82 |
| Ca (μg) | 30 | 114 |
| Mg (μg) | 11 | 18 |
| Fe (μg) | 0.30 | 1.63 |
| Na (μg) | 67 | 18 |
| Zn (μg) | 0.27 | 0.16 |
| Vitamin C (mg) | 21.0 | 25.8 |
| Vitamin B1 (mg) | 0.040 | 0.044 |
| Vitamin B2 (mg) | 0.30 | 0.88 |
| Vitamin B3 (mg) | 0.400 | 0.388 |
| Pyridoxine | 0.90 | 0.074 |
| Folate DFE (mg) | 15 | 41 |
| Tocopherol (mg) | 0.30 | 0.00 |
| Phylloquinone (mg) | 0.1 | 0.00 |
| Vitamin A (IU) | 0.0 | 6108 |

Adapted and modified from USDA 2018

othernon-nutritive compounds, which provide desirable health benefits, like antibacterial properties, anti-carcinogenic properties, increase the immune system in human body beyond basic nutrition (Haliloglu et al. 2012). The antioxidant property exhibited by the non-nutritive compounds (polyphenols, flavonoids, isoflavones and glucosinolates) present in turnip assists the body to scavenge harmful free radicals and may therefore protect tissues against oxidative damages, prevention from cancers, inflammation and helps to boostimmunity (Silva et al. 2004). The intake of natural antioxidants from turnip is necessary for healthy life because the high antioxidant property of *Brassica* species showed a protective effect on the oxidation of lipoproteins (Kural et al. 2011).

## 7.2 Antioxidant Activity

More than 30% of degenerative diseases including cancers are linked to oxidative damage of tissues by free radicals, imbalanced diet, and other correlated factors (Czapski 2009). Epidemiological studies have indicated that intake of natural antioxidants from foods (fruits and vegetables) improves health and lowers mortality rate due to cancers and other degenerative diseases. Brassicaceous plants (*Brassica* *rapa*) are consumed in large quantities because of high dry matter digestibility and vital secondary metabolites like glucosinolates, isothiocyanates, flavonoids, isoflavones, polyphenols, carotenes, anthocyanins, zeaxanthins, folacin, selenium, lutein, and ascorbic acid. These secondary metabolites have high antioxidant capacity and play an imperative protective role against different types of cancers and cardiovascular and other degenerative diseases resulting from various factors by inhibiting the negative effects of free radicals (Haliloglu et al. 2012). These metabolites have beneficial properties on human health because of anti-carcinogenic properties and work strongly against different types of cancer-causing agents (Zhao et al. 2007; Cartea and Rodriguez 2008). The presence of phytochemicals (glucosinolates, polyphenols, isothiocyanates, flavonoids, carotenes, terepenes, aldehydes, esters and other compounds in turnips are responsible for antioxidant activity and chemoprotective property Pierre et al. (2011).

### 7.2.1 Glucosinolates and Isothiocyanates

Glucosinolates and their derived compounds are the distinctive constituents of turnip indicating beneficial properties on human wellbeing because of wide range of bioactivities (Rosa et al. 1997) (Table 7.2). Glucosinolate is a vital phytochemical normally found in *Brassica* vegetables in amounts of 1500–2000 μg/g (Ehlers et al. 2015). The basic structure of glucosinolate comprises a β-D-thioglucose group, sulfonated oxime (-C=NOH) group, and a variable side chain derived from amino acids. The side chain (R) comprises of an aliphatic (alkyl, alkenyl, hydroxyalkenyl, w-methylthioalkyl, w-sulfinyl and w-sulfonylalkyl), aromatic (benzyl) orheterocyclic (indolyl) groups in the highly variable structure. A little variation inside the chain leads the development of various glucosinolates (Holst and Williamson 2004).

Isothiocyanates are potentially anti-carcinogenic and anti-mutagenic phytochemicals which are being produced from the metabolism of glucosinolates (Cartea and Rodriguez 2008). Roughly 100 isothiocyanates have been recognized; however just a couple of them are common in the eating routine and are present in a couple of chosen nourishments like *Brassica* vegetables. Isothiocyanates decrease systemic oxidative levels, instigate apoptosis, restrain cell cycle progression, repress angiogenesis, and furthermore show anti-bacterial, anti-viral, and anti-cancer properties (Fowke et al. 2011). Two fundamental mechanisms have been proposed for the chemopreventive impact of isothiocyanates. The first mechanism is identified with inactivation of the stage I enzyme cytochrome P450s attaching with an isothiocyanate, just as the induction of the stage II enzymes. The other mechanisms include the induction of apoptosis which causes the erasure of genetically harmed cells and halting of the progression of the cell cycle (Kalpana Deepa Priya et al. 2013).

**Table 7.2** List of glucosinolates and isothiocyanates found in turnip plant

| Origin | Compounds | References |
|---|---|---|
| Leaves | 2-Hydroxy-3- butenyl (Progoitrin) | Yang and Quiros (2010) and Cartea and Rodriguez (2008) |
| | 4-Pentenyl (Glucobrassicanapin) | Cartea and Rodriguez (2008) |
| | 5-Methylsulfinylpentyl (Glucoalyssin) | Cartea and Rodriguez (2008) |
| | 4-Methylsulphinyl-3-butenylglucosinolate (Glucoraphanin) | Francisco et al. (2009) |
| | Indol-3-ylmethyl (Glucobrassicin) | Francisco et al. (2009) and Cartea and Rodriguez (2008) |
| | 3-Butenyl (Gluconapin) | Francisco et al. (2009) and Cartea and Rodriguez (2008) |
| | 4-Hydroxy-3-indolylmethyl glucosinolate (4-Hydroxyglucobrassicin) | Yang and Quiros (2010) and Cartea and Rodriguez (2008) |
| | Dihydrogluconapin | Francisco et al. (2009) |
| | 1-Thio-beta-D-glucopyranose 1-[N-(sulfooxy)-5-hexenimidate] Glucobrassicanapin | Yang and Quiros (2010) |
| | Benzyl glucosinolate (Glucotropaeolin) | Francisco et al. (2009) |
| Roots | 1-Methylpropyl glucosinolate (Glucocochlearin) | Yang and Quiros (2010) |
| | 5-Methylthiopentyl isothiocyanate (berteroin) | Afsharypuor and Tahmasian (2010) |
| | Isothiocyanatomethylbenzene (Benzyl isothiocyanate) | Robin et al. (2018) |
| Leaves, roots | 4-Methoxy-3-indolylmethyl glucosinolate (4-Methoxyglucobrassicin) | Lee et al. (2013) |
| | 5-Methylthiopentyl glucosinolate (Glucoberteroin) | Lee et al. (2013) |
| Roots and seeds | 2-Phenylethyl isothiocyanate (Phenethyl isothiocyanate) | Afsharypuor and Tahmasian (2010) |
| Seeds, leaves | 3-Buten-1-yl Isothiocyanate (3-Butenyl isothiocyanate) | Afsharypuor and Tahmasian (2010) |
| Seeds, sprouts | 2-Isothiocyanatopropane (Isopropyl isothiocyanate) | Taveira et al. (2009) |
| | Prop-2-en-1-yl thiocyanate (Allyl thiocyanate) | Taveira et al. (2009) |
| | 3-isothiocyanatoprop-1-ene (Allyl isothiocyanate) | Robin et al. (2018) |
| | 2-Isothiocyanatobutane (2-butyl isothiocyanate) | Taveira et al. (2009) |
| | 1-Isothiocyanato-3-methylbutane (3-Methylbutyl isothiocyanate) | Taveira et al. (2009) |
| | 1-Isothiocyanatopentane (Pentyl isothiocyanate) | Afsharypuor and Tahmasian (2010) |
| | 1-Isothiocyanatohexane (Hexyl isothiocyanate) | Lee et al. (2013) |

Adapted and modified from Paul et al. (2019); Martinez et al. (2010); Cartea and Rodriguez (2008)

### 7.2.2 Flavonoids

The flavonoid compounds are secondary metabolites extensively distributed in *Brassica* species in the form of glycosides. The *Brassica* genus is relatively high in flavonoids and other bioactive compounds having positive effects on human health compared to other high-water-content vegetables. Flavonoids and hydroxycinnamic acids are the most widely recognized and heterogeneous groups of polyphenols in the *Brassica* genus. The percentage of phenolic compounds (flavonoids) varies from 57.71 to 38.99 μmol/g among the different parts of turnip (Francisco et al. 2009). These compounds exhibit free radical quenching property by hindering the biological activation of cancer-causing compounds and by expanding the detoxification of reactive oxygen species (ROS) (Morales-Lopez et al. 2017). Flavonoid-rich diet is vital for the healthy life because it protects against cardiovascular diseases, coronary artery diseases, pigmentation and other degenerative disease resulting from imbalance in antioxidant and other status of the persons (Crozier et al. 2006). Phenolic compounds are scientifically classified as simple compounds, low molecular weight compounds, single fragrant cyclic compounds, enormous and complex tannins, and derivatized polyphenols. They are sorted based on the number and frame-up of carbon molecules in flavonoids as flavonols, flavones, flavan-3-ols, anthocyanidins, flavanones, isoflavones, and others and non-flavonoids as phenolic acids, hydroxycinnamates, stilbenes, and others. They are available in high concentration in the epidermis of leaves and fruit. Of the 35 flavonoids reported from this plant, kaempferol, quercetin, and isorhamnetin are the most well-known aglycones. The main flavonoids present in turnip are presented in Table 7.3.

### 7.2.3 Other Compounds

Besides the pro-health benefits of abovementioned compounds, recent research articles showed that *Brassica* species are a good source of other compounds involving phytochemicals, nitrates, alcohols, indoles, lignans, aldehydes, sesquiterpene, phenylpropanoids, phenylglycosides, sulfurous compounds, carbohydrate derivatives, and other bioactive compounds which are listed in Table 7.4.

**Table 7.3** The main flavonoid compounds present in turnip

| Origin | Compound | References |
|---|---|---|
| Leaves | Kaempferol | Francisco et al. (2009) |
| | Quercetin | Francisco et al. (2009) |
| | Isorhamnetin | Francisco et al. (2009) |
| Roots | Liquiritin | Jeong et al. (2013) |
| | Liquiritigenin | Jeong et al. (2013) |
| | Isoliquiritin | Jeong et al. (2013) |
| | Licochalcone A | Jeong et al. (2013) |

Adapted and modified from Paul et al. (2019) and Martinez et al. (2010)

**Table 7.4** Other bioactive compounds present in turnip

| Origin | Compound | References |
|---|---|---|
| Roots | 1-Methoxy-1H-indole-3-acetonitrile (caulilexin C) | Bang et al. (2012) |
| | Arvelexin | Bang et al. (2012) |
| | 2-(1H-indol-3-yl)acetonitrile (Indoleacetonitrile) | Bang et al. (2012) |
| | Dihydrosyringin | Wu et al. (2013a) |
| | Brassicaphenanthrene A | Wu et al. (2013b) |
| Leaves | Caffeic acid | Francisco et al. (2009) |
| | Sinapic acid) | Francisco et al. (2009) |
| | (2E)-3-(4-hydroxy-3,5dimethoxyphenyl)prop-2-enoylD-glucopyranoside (Sinapoylglucoside) | Francisco et al. (2009) |
| | 3-caffeoylquinic acid | Francisco et al. (2009) |
| Aerial parts | Beta-glucopyrane-4-oxyacetophenone (Picein) | Ninomiya et al. (2010) |
| | Acetosyringyl-beta-glucoside (Glucoacetosyringone) | Ninomiya et al. (2010) |
| | 3-O-beta-D-Glucopyranosyl-5,6-epoxy-9-hydroxyionol (Corchoionoside) | Ninomiya et al. (2010) |
| Seeds | 3-phenylpropionitrile(Benzenepropanenitrile) | Robin et al. (2015) |
| | Sinapine thiocyanate | Fu et al. (2016) |

Adapted and modified from Paul et al. (2019) and Martinez et al. (2010).

Furthermore, several of these compounds function as potential therapeutic agents against different degenerative diseases, anti-inflammatory modulators, hepatoprotective agents, phytoestrogens, antioxidants, enzyme- activated irreversible inhibitors and anti-carcinogenic agents.

### 7.2.4 Volatiles

The volatile compounds of the plants are significant organic compounds responsible for the characteristic flavor and aroma. *Brassica* plants are wealthy in unpredictable natural mixes with known bioactivities gainful to human wellbeing. These are of two kinds: direct (fundamentally in the plant) and indirect (herbivore-instigated plant volatiles, HIPVs) types. Herbivorous assault on plants brings about the arrival of certain unstable compound which can be moved between the neighboring plants as compound signs for self-assurance. Turnips are rich source of bioactive volatile

**Table 7.5** Volatile compounds present in turnip

| Origin | Compound | References |
|---|---|---|
| Leaves, roots | 2-Hydroxybenzaldehyde (Salicylaldehyde) | Pierre et al. (2011) |
| | Octadecanal (Stearaldehyde) | Pierre et al. (2011) |
| | Heptadecene (Hexahydroaplotaxene) | Pierre et al. (2011) |
| | Ethanoic acid (acetic acid) | Pierre et al. (2011) |
| | Methyl 2-hydroxybenzoate (methyl salicylate) | Pierre et al. (2011) |
| | Ethyl ethanoate (Ethylacetate) | Pierre et al. (2011) |
| | Hexyl ethanoate(Hexylacetate) | Pierre et al. (2011) |
| | Hexanoic acid(Caproic acid) | Pierre et al. (2011) |
| Adult plants | Undecanal (Undecanaldehyde) | Taveira et al. (2009) |
| | Undec-10-enal (10-undecanal) | Taveira et al. (2009) |
| | Dodecyl aldehyde (Dodecanal) | Taveira et al. (2009) |
| | Ethyl pentanoate( Ethyl valerate) | Taveira et al. (2009) |
| Adult plants, sprouts | Ethyl octanoate ( Ethyl caprylate) | Taveira et al. (2009) |
| | 2,3-Dihydro-2,2,6-trimethylbenzaldehyde (safranal) | Taveira et al. (2009) |
| Adult plants, sprouts, seeds | Hexanal(Caproaldehyde) | Taveira et al. (2009) |
| | Nonanal(Pelargonaldehyde) | Taveira et al. (2009) |
| | 3-Phenylpropanenitrile (Benzenepropanenitrile) | Taveira et al. (2009) |

Adapted and modified from Paul et al. (2019) and Martinez et al. (2010)

organic compounds which are mainly composed of carbonyls, nitrogen, and sulfur compounds. These volatiles are ubiquitous and are produced via metabolic pathways that unfold during ripening, harvesting, and storage conditions (Heil 2008). These bioactive volatiles have the potential to act as barrier signals against microbial and herbivorous assault and protect against different degenerative diseases including diabetes and cardiovascular diseases. Diverse volatile compounds present in turnip are listed in Table 7.5.

## 7.3 Health Benefits of Turnip

Phytochemicals present in *Brassica* vegetables show different effects that prevent oxidative stresses, induce detoxification enzymes, stimulate the immune system, reduce the proliferation of cancer cells, and inhibit malignant transformation and carcinogenic mutations (Horst et al. 2010). They protect the human body against reactive oxygen species (ROS) that may cause DNA damage, modulation of gene expression, base modification, and oxidation of lipid and protein present in the body. Members of the *Brassicaceae* family are known for their anti-carcinogenic effects and also have protective effects on genetic material (Kapusta-Duch et al. 2012). They also play an important role in the etiopathology of many diseases such as vasospasm, atherosclerosis, cancers, heart attack, stroke, and liver damage (Kapusta-Duch et al. 2012)**.** The main beneficial effects on health are discussed below:

### 7.3.1 Hepatoprotective Activity

Liver is a vital organ that plays a pivotal role in the metabolism of xenobiotics. Liver diseases are a global health issue, and the conventional therapies are suboptimal due to their serious side effects (Rafatullah et al. 2006). Consumption of herbs and vegetables has received great attention due to beneficial effects in treating liver-related problems (Li et al. 2010). Besides being an important vegetable, turnip is having antiscorbutic, antiarthritic, stomachic, and laxative properties (Rafatullah et al. 2006). The turnip extract contains high content of glucosinolates, isothiocyanates, flavonoids, phenols, indoles, volatiles and sulfur compounds that have been medicinally used to treat headaches, chest complaints, gastritis, constipation and other diseases because these bioactive compounds neutralizes the reative oxygen species that otherwise cause destruction to the structure and function of liver (Choi et al. 2006).

### 7.3.2 Nephroprotective Activity

According to various studies, health-promoting compounds such as flavonoids (isorhamnetin-3-*O*-glucoside) are present in turnips that are able to suppress oxidative stress, lipid peroxidation, and reactive oxygen species (ROS) production which are responsible for nephrotoxicity (Kim et al. 2006; Mohajeri et al. 2013).

### 7.3.3 Antidiabetic Activity

Diabetes is a chronic, metabolic disorder that impairs body’s ability to process blood sugar and leads to serious damage to vital organs involving the heart, blood vessels, eyes, kidneys, and nerves. Therapy has been based on drug that stimulates insulin secretion for treating diabetes is available in market but all of these drugs have various side effectslike kidney complications, hypoglycemia and drug resistance which limits their application. Turnip extracts from roots and leaves contain biologically active compounds such as isorhamnetin, quercetin, kaempferol, indole alkaloids, etc. which have showed antidiabetic effects in type 2 diabetic mice (DaryoushM et al. 2011).

### 7.3.4 Anti-cancer Activities

Cancers are the most serious health problems in the world leading to million deaths every year. Studies have revealed that the higher intake of turnips can reduce cancer chances because it contains more phytochemicals like glucosinolates, 2-phenylethyl isothiocyanate, 3-phenylpropionitrile, di-indolylmethane, sulforaphane, and indole-3-carbinol, which are potential inhibitors of DNA oxidative damage and mutagens, making them effective at preventing cancers and tumors and also allowing the body to better detoxify harmful chemicals (Zhang et al. 1994; Robin et al. 2015).

### 7.3.5 Anti-bacterial Properties

Plants are the basis of medicines from ancient years and continue to provide new remedies to cure diseases. The use of natural products as antimicrobial agents has increased because of limited application of drugs. The increased resistance of microorganism to drugs and the side effects of drugs threaten public health. The turnip extracts have been proposed to be very effective against most of the pathogenic microorganism in folk medicine. The quercetin glucosinolates, isothiocyanates, flavonoids, phenols, indoles, volatiles, sulfur compounds, and other biological compounds present in turnips are medicinally used to control bacterial as well as fungal infections (Hong and Kim 2008).

### 7.3.6 Analgesic Activity

Synthetic analgesics to control the pain and its complications may cause gastrointestinal problems and other side effects when consumed over a long period. Due to the suboptimal application of synthetic analgesics, new studies have been conducted to find alternative to alleviate pain and to have less side effects when consumed. Turnip and the alcoholic extracts of turnip have been recognized as important sources for natural analgesic (reduces pain) because turnip extracts showed significant decrease in pain score in both acute and chronic phases in male mice (Hosseini et al. 2013).

### 7.3.7 Anti-inflammatory Effect

Inflammation is part of the body's immune response to harmful stimuli, pathogens, damaged cells, or other irritants. Turnip is considered one of the important sources of chemicals having anti-inflammatory properties (Bang et al. 2012). Studies have revealed that during prostaglandin synthesis from arachidonic acid which occurs in response to inflammatory stimuli, flavonoids present in turnip have shown inhibitory action on cyclooxygenase enzyme, preventing sensitization of pain receptors and reducing the pain sensation associated with the response (Shin et al. 2011).

### 7.3.8 Antioxidant Properties

Studies have revealed that turnip is a good source of antioxidants due to the presence of biologically active compounds. The natural antioxidants (quercetin, tocopherols, ascorbic acid and beta- carotene) present in turnip enhances the degradation of bad cholesterol from the body, protects the heart and reduces the chances of atherosclerosis (Chaudhary et al. 2016). A balance between free radicals and antioxidants is necessary for proper physiological function. Free radicals adversely alter lipids, proteins, and DNA and trigger a number of human diseases. Antioxidants present in turnip protects the vital organs of the body like liver, heart, kidney from the harmful action of free radicals by breaking the free radical chain and protects the cells from free radical damage (Daryoush et al., 2011).

## 7.4 Conclusion

Vegetables of the *Brassica* group are extensively distributed worldwide, and regular consumption of a turnip-rich diet has undeniable positive effects on health since phytochemicals like glucosinolates, isothiocyanates, thiosulfides, flavonoids, indoles, sulfur compounds, etc. of turnips can protect the human body from several types of degenerative diseases. They are economically the most important and widely cultivated crop in the temperate climates of the globe and have witnessed a constant ascending development throughout the past few decades. Turnips have a high nutritive and dietetic value that derives from its rich phytochemical composition. Turnip is a well-known food source for both the root and greens and is considered essential for well-balanced diet since they supply vitamins, minerals, and dietary fiber. Turnip forage has been shown to remain high in nutritive composition well into the fall and early winter months, thus providing a fresh forage alternative to stored forage or purchased feeds. Moreover, it is important that the high nutritive value of *Brassica* forage be taken into account when balancing rations for ruminant animals.

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# Spinach (*Spinacia oleracea* L.)

8

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**Abstract**

Recent insights about food and nutrition signify that the consumption of fresh produce is defensive to general acute and chronic disorders. Dark green leafy vegetables are acknowledged to ameliorate these symptoms as they possess abundant nutrients and biological properties. *Spinacia oleracea* (spinach) is widely available and accepted traditional green, leafy vegetables in the world: it is an excellent choice for micronutrients and phytonutrients. Thus, the consumption of this vegetable is recommended on a regular dietary regimen. The phytochemicals and bioactives that are derived from spinach (raw and cooked) are capable of a) scavenging singlet oxygen species and inhibit oxidative stress, b) alter gene expressions that are associated with metabolic activities, tumors, acute and chronic inflammation, and antioxidant system, and c) diminish diet intake by altering hormones involved in obesity. These biological activities are associated with various metabolic disorders. Hence, regular consumption of spinach would provide a qualitative well-being against cancer, obesity, hyperglycemia, and hyperlipidemia. This chapter provides insights about the functional

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and biological properties of spinach involved in different investigations. The mechanistic process of spinach and spinach-derived phytochemicals imparting health benefits is explored.

**Keywords**

Spinach · Phytochemicals · Metabolic activities · Oxidative stress · Health benefits

## 8.1 Introduction

**Botanical Name, common name and scientific classification.**

*Spinacia oleracea* is generally known as Spinach (English). The other native forms of the names are as follows:

Sanskrit: Chhurika.
Hindi, Gujarati, Marathi: Palak.
Kashmiri: Palakh.
Bangla: Palang.
Tamil: Pasalai.
Telugu: Mathubucchali (Guha and Das 2008).

The ayurvedic name of spinach is "Paalankikaa." It is known as "Paalak" and "Vasaiyila-keerai" in Unani and Siddha, respectively (Khare 2007). The plant profile and the scientific classification is provided in the Table 8.1.

Spinach is originally a leafy vegetable which is dark green in color belonging to the Amaranthaceae family, which includes beets and chard (Morelock and Correll 2008). It is commonly annual and rarely biennial plant. Generally, it reaches 30 cm height and can survive even low temperatures in temperate regions. Spinach is broadly categorized corresponding to their leaf texture. This contains three variants:

**Table 8.1** Scientific classification of *Spinacia oleracea* L.

| Kingdom | Plantae |
|---|---|
| Subkingdom | Tracheobionta |
| Super division | Spermatophyta |
| Division | Magnoliophyta |
| Class | Magnoliopsida |
| Sub class | Caryophyllidae |
| Order | Caryophyllales |
| Family | Chenopodiaceae |
| Genus | Spinacia L. |
| Species | *Spinacia oleracea L.* |

Source: Natural Resources Conservation Service www.plants.usda.gov smooth, savoy, and semi-savoy. Smooth spinach leaves are recommended for salads and processing, meanwhile, the other two are widely used for cooking. Among the three variants, savoy is dark green in color with wrinkled and wavy leaves. On the other hand, semi-savoy is a crossbreed variant and has marginally wrinkled leaves and is considerably simpler to process than traditional savoy. As the name says, smooth-leaved spinach is observed to have exceptionally smooth leaves. Spinach is adaptable with all culinary process with health-benefitting bioactive nutrients. Therefore, it is highly desired among all populations (Nishihara et al. 2001). It is available and can be cooked even during the winter periods or can be processed as canned or frozen product. Despite low-calorie content, spinach provides greater amount of phytonutrients and antioxidants. Also, they have abundant levels of iron and calcium. Additionally, spinach is a great resource of flavonoids. They exhibit biological properties against reactive oxygen species, cancer, inflammation, gamma radiation, and weight gain. Spinach is similarly employed in the prevention and treatment of bone loss linked with ageing and osteoporosis and aims at reducing the pain and inflammation in arthritis. Spinach is an absolute choice for energy boosting and has beneficiary effects on the heart and circulatory system. The other potential health benefits of spinach consumption include improved blood glucose control, lowered risk of cancer, and improved bone health (Metha and Belemkar 2014). Spinach is largely comprised of water (91.4%), protein (2.9%), carbohydrate (3.6%), and fat (0.4%). The lipid portion is primarily comprised of mono- and poly-unsaturated fatty acids with trace amounts of saturated fatty acids. Serving of 100-g spinach includes higher concentrations of magnesium, potassium, and iron and meets 20%, 16%, and 15% individually of their recommended dietary allowance (Elvira-Torales et al. 2019). The micronutrient composition is significantly diverse compared to other generally used green leafy vegetables.

### 8.1.1 History

Spinach, being consumed by human race through various cultures throughout history, is notably employed in the Mediterranean, Middle Eastern, and southeast Asian cuisines. The origin of spinach was believed to be from Persia (Iran). Apparently, spinach got its attention across other portions of Asia and Europe via the trading process. (Hu et al. 2007) The ancient documents of spinach are recorded by the Chinese in 647 A.D., and it was specified as the herb of Persia. (Morelock and Correll 2008). The spinach was immensely popular in the twelfth century and reached Spain. Spinach was accepted in England and France during the fourteenth century from Spain. Germany had the knowledge regarding the thorny-seeded variant spinach around the thirteenth century while the smooth seeded spinach variant arrived in the sixteenth century. It became remarkably familiar there since the production escalated in spring, while there was a scarcity for all other vegetables in that cycle of history (Adamson 2004). “The Forme of Cury” is the earliest English cookbook, to mention cookery recipes involving raw and processed spinach. Catherine de’ Medici, the queen of France in 1533, consumed spinach on a regular diet regimen, and spinach acquired wider acceptance during her era. In the course of the World War I, French soldiers who were hurt from hemorrhage were offered wine blended with extracts from spinach. Throughout those periods, more effective variations of spinach were planted widely (Pegge 2006).

### 8.1.2 Production (India, World)

Spinach is produced in cool season, so the plant is mostly grown during winter and early spring. Spinach is harvested before the seed stalk develops. The spinach is cut off about an inch above the soil surface. It can be cultivated on every kind of topsoil getting decent drainage capability. It provides better yield while grown on a combination of sandy and alluvial soil, and the optimum pH of the soil for spinach growth should extend from 6 to 7. The optimal temperature for growth ranges between 15 and 30 °C with the rainfall of 80–120 cm. While harvesting, well-grown succulent and tender leaves will be trimmed. On an average, the crop can undergo 4–6 trims. The entire yield of spinach can range between 80 and 100 quintals per hectare land (Simko et al. 2014). In India, Telangana, Kerala, Tamil Nadu state, Karnataka, Maharashtra province, and Gujarat are the leading producers of spinach (Singh et al. 2018a, b).

### 8.1.3 Botanical Description

The botanical description of this plant includes stem, leaves, and flowers. The spinach plant is generally observed with simple leaves that stems from the axis. This usually measures around 2–30 cm long and 1–15 cm wide. The shoots develop in a rosette and are commonly wrinkled or flat. The crop creates small creamy-green blooms that are 3–4 mm thick. The blooms generate small fruit bundles that will cover the seeds within. The stem portion is usually vertical with 30 cm tall, rounded, soft, and succulent(Zikalala 2014). Spinach leaves are complementary in structure, with long petiole, with sections of a sharp three-sided structure and are soft mutually on the perimeters. The male flowers are observed in the axial region with short structures. The calyx is generally 4-parted and twinned anthers are present. Female flowers are axillary, sessile, and congested. Calyx are 2-tipped along with a projecting point on both the sides, developing into spikes during the ripening of seeds (Kirtikar and Basu 2005).

## 8.2 Characterization of the Chemical Compounds Responsible for Antioxidant Proprieties and the Pathways Involved in the Biological Activities

Spinach is an excellent source of micronutrients of not only vitamins but also of flavonoids, phenols, and carotenoids. The list of chemical compounds abundant in spinach is given below.

### 8.2.1 Flavonoids

Spinach is immensely rich in the flavonoids. Numerous flavonoids including querecetin, myricetin, spinacetin, luteolin, jaceidin, patuletin, lutein epoxide, neoxanthin, glucuronic acid 3,5,7,3′,4’pentahydroxi-6-methoxiflavone, pheophytin b, neoluteinare documented to be detected in spinach (Kaur et al. 2016).

### 8.2.2 Phenolic Compounds

Spinach is a better source of phenolic compounds and carotenoids. The polyphenols detected from the spinach and spinach derived extracts are para-coumaric acid, ortho-coumaric, and ferulic acid. Spinach also illustrates the existence of various carotenoids like lutein, 9′-(Z)-neoxanhin, violaxanthin and β-carotene, (Hedges and Lister 2007).

### 8.2.3 Vitamins and Minerals

Spinach comprises of high-level of vitamin A, C, E, and K. Also; it is similarly rich in folic acid. Along with these health-promising compounds, a variety of minerals are available in spinach and spinach-derived extracts including calcium, manganese, magnesium, iron, copper, zinc, potassium, and phosphorus (Joseph et al. 1998).

## 8.3 Antioxidant Properties and Mechanisms Involved

Spinach is renowned for its antioxidant beneficial mechanisms. The antioxidant mechanism of spinach isolate was demonstrated in vitro observed on eradicating ABTS (2,2′- Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) radical, superoxides ($O2^-$), $Fe2^+$, peroxynitrite, peroxyl, and hydroxyl radical. Derivatives from spinach demonstrated elevated overall free-radical-scavenging capacity. Spinach extracts used in vitro studies demonstrated that they aim at preventing (~35%) the peroxide production and malondialdehyde (MDA) generation due to oxidative stress (Singh and Rajini 2004). Spinach and spinach-derived extracts also include derivatives of the antioxidant flavonoids like glucuronide, patuletin, neoxanthin, and spinacetin.

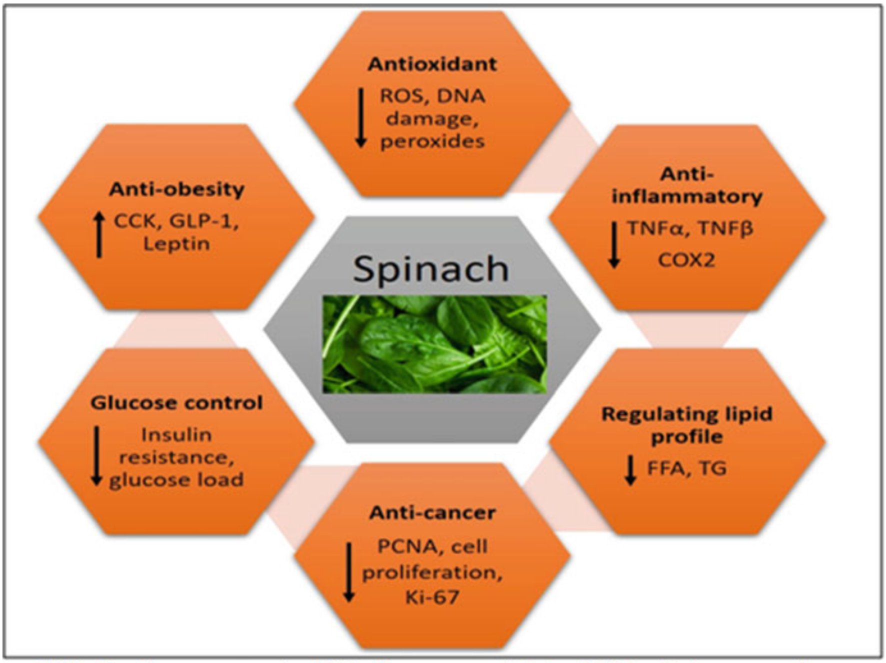
Specifically, acylated flavonol glycosides from spinach comprising of patuletin and its derivates and the glucuronated flavonoid established the maximum antioxidant ability in vitro (Bergman et al. 2003). The antioxidant mechanism of spinach and spinach-derived extracts was analyzed in laboratory rodents. Spinach powder that is freeze-dried displayed considerably lowered lipid peroxidation levels in liver and DNA damage of the leukocytes (Ko et al. 2014).

In another experiment, 0.64% of spinach-derived extract was supplemented for Fischer rats over 8 months and was observed that there was substantial reduction in 2′,7′-dichlorofluorescin generation, which is a notable indicator of free radicals in the striatum and cerebellum (Lomnitski 2000a). In a separate experiment, spinach-derived extract (1% suspension) was superficially applied and exhibited better effects than 5% vitamin E in suspended form against malonaldehyde generation and reducing lipo-oxygenase activity. This was observed in the epidermal layer of UV-exposed experimental mice. Plasma lipid peroxidation and superoxide (H2O2) levels in these animals were considerable reduced (−15%) than the control ones. Along with the above-mentioned evidence, spinach and spinach-derived extracts contain higher levels of glycosylated derivatives of para-coumaric acid and flavonoids (Wang 2018). Clinical studies have also offered a few data about the antioxidant mechanism of spinach.

An exclusive study on elderly women was conducted (age = 66.9 year and n = 7–8). This showed that inclusion of spinach in every meal (294 g) had greatly impacted the ORAC (oxygen radical absorbance capacity), TEAC (Trolox equivalent antioxidant capacity), and FRAP (ferric reducing capacity of plasma) (+25%), (+24%), (+21%) respectively post 4 h than the control population without spinach consumption (Heim et al. 2002). Another 2-week study on males with the regular intake of spinach powder (10 g suspended in milk or water) had reduced DNA damage and repaired strand breakage in lymphocytes. In this research, plasma lutein levels were observed to be hiked by 2-folds post consumption of spinach powder. Also, spinach scavenges superoxide anions and hydroxyl radicals, increases serum lutein, and induces antioxidant enzymes comprising of catalase, superoxide dismutase, glutathione reductase, and glutathione. In an exclusive study 48 healthy male and female subjects were subjected to consume raw or cooked 20 g spinach/day for 3 weeks. The results showed improved plasma lutein levels and erythrocyte glutathione reductase levels. Apparently, all these clinical investigations support the perception that spinach, and its derived extracts, enhances oxidative defense mechanism involving the upregulation of antioxidant enzymes and its representative genes (Roberts and Moreau 2016).

## 8.4 Health Benefits

Every diseases and disorders are usually associated with current pharmacological therapies. Apparently, most of these are related with unfavorable and irreversible side effects including nausea, aversion, constipation, faintness, and even weight gain. Hence, functional foods are alluring substitutes in the therapy and prevention




ROS – Reactive oxygen species, TNF – Tumour necrosis factor, COX2 – Cyclooxogenase 2, FFA – Free fatty acids, TG – Triglyceroids, PCNA - Proliferating cell nuclear antigen, Ki-67 – Marker protein for cell proliferation, CCK – Cholecystokinin, GLP-1 - Glucagon-likepeptide 1.

**Fig. 8.1** Functional properties and health benefits of spinach

of lifestyle disorders (Frewer et al. 2003). The functional properties and the health benefits of spinach are given in Fig. 8.1.

### 8.4.1 Anti-inflammatory Properties

Immune responses occurring naturally to any biological infection are inflammation. Long-term inflammation can cause severe and persistent disorders including cell proliferation, cardiac disease, and type-2 diabetes mellitus (Manabe 2011). The anti-inflammatory potential of spinach was investigated in different laboratory animals. Spinach-derived extracts (10 mg/kg via i.p.) were supplemented to male Wistar rats for 8 successive days and then was administered with a dose of lipopolysaccharide (LPS-10 mg/kg via i.p.). The results exhibited reduced hepatic lacerations caused by LPS-induction and, diminished cyclooxygenase-2 (COX-2) production, which creates the initiation of inflammatory cells (e.g., monocytes, polymorphonuclear leukocytes). Correspondingly, laboratory rabbits in New Zealand receiving spinach extracts (10 mg/kg, via i.p.) were examined with LPS (10 mg/kg via i.p.) for 8 consecutive days and were found to reduce lesions in major organs caused by

LPS treatment. It is well known that LPS stimulates inflammation via toll-like receptor-4 (TLR-4) and regulating nuclear factor kappa B (NF-κB), in the cytoplasm attached to the inhibitory protein (IκB). During this process, LPS is bound to TLR-4 and stimulates the phosphorylation and initiation of IκB kinase (IKK), and IκB is phosphorylated. IκB goes through proteasomal modification, permitting NF-κB to the nucleus by dimerization and translocation where NF-κB initiates the expression of pro-inflammatory cytokines, eicosanoids, and free radicals (Lomnitski 2000b).

The aromatic phenolics including para-coumaric acid in spinach extracts provide notable anti-inflammatory properties (Fan et al. 2011). Fischer rats were supplemented with 0.02% (w/w) dry spinach for 6 weeks and it was observed that the expression of NF-κB mark genes, TNF-α and TNF-β, reduced in the cerebellum region. The anti-inflammatory potential of lutein, which is a carotenoid having increased bioavailability, has been involved with investigation on animal simulations and human trials (Ciccone et al. 2013). BALB/c mice administered with lutein (10 mg/kg via i.p.) tested with LPS exhibited that the plasma concentrations of prostaglandin E2 (PGE2), TNF-α, and IL-1β, along with reduced loads of iNOS and COX-2 enzymes in liver (Anchi et al. 2017). LPS-induced peritoneal macrophages administered with 20 μM lutein showed modified levels of PGE2, TNF-α, and IL-1β. The above results determined that, by eradicating free radicals, lutein reduced the accessibility of H2O2 to trigger IKK-dependent activation of NF-κB, thus reducing NF-κB target gene expression (Vats 2017). Spinach also comprises of significant levels of β-carotene and mimics the anti-inflammatory potential of lutein via similar mechanisms. Further investigation in clinical trials is necessary to validate these findings involving the consumption of spinach and spinach extracts or foods rich in lutein, reducing inflammation in animals via inflection of the NF-κB pathway (Aman et al. 2005).

In gastrointestinal epithelial cells (AGS cells), H2O2-induction and NF-κB activation was inhibited by β-carotene and was observed with reduced levels ofinterleukin-8 (IL-8), a proinflammatory chemokine. Crucially, the bioavailability of β-carotene is much lesser than lutein, since both the carotenoids link up adversely with each other all through the intestinal absorption process. Since the level of lutein in spinach is considerably greater than β-carotene, the anti-inflammatory process is majorly facilitated by lutein. A randomized, double-blind test was conducted, and 25 healthy men and women were provided dried spinach (10.4 g/day) for 8 weeks with placebo-controlled trial for finding the effects of spinach on inflammation. Participants exhibited a substantial rise in serum lutein with the consumption of dried spinach. Therefore, the findings from laboratory animals and cell culture studies suggested that lutein from spinach eradicates the inflammatory reaction by reducing the initiation of NF-κB, and recommended that addition of lutein-enriched foods, like spinach, may possibly suppress inflammation (Madaan et al. 2017).

### 8.4.2 Antiproliferative Properties

Globally, cancer is a growing lifestyle-based disorder and affects people irrespective of age and gender. Existing statistics indicate that the prevalence percentage of this disease will hike by 70% in the upcoming decades (Yang 2006). It is a primary priority to address this issue with steadfast and effective approaches to restrict and heal cancer. Among the various causes combined with carcinogenesis, the impact of food on hyperplasia is fairly determined. Eating patterns with the incorporation of dark green vegetables are well correlated with a diminished probability for several cancers (Neuhouser 2004). Epidemiological investigations have exhibited a defensive function of spinach intake various types of cancers (Scalbert et al. 2005).

In a case-control study on women who had raw spinach (>52 portions/year) showed 45% reduced chance of breast cancer. Lutein, one of the carotenoids, was particularly connected with a decreased danger of breast cancer (Gaudet et al. 2004). Colon cancer probability was decreased 11% with one serving of spinach (73 g/ week) on a regular dietary regimen. In a cohort study of 4,90,802 participants, it was observed that the consumption of spinach in raw or cooked form was linked with a notable decline in esophageal adenocarcinoma (Freedman et al. 2007). The chemoprotective activities of spinach have been examined mutually in animal models and cancer cell lines. Spinach-derived extracts 200 mg/kg/day administered orally increased the proliferation in dorsal and lateral sections of pancreas. Spinach acts as an antiproliferative agent and with consumption of spinach for 2 weeks significantly repressed proliferation of colon epithelial cells that is heme-induced in Wistar rats. These defensive effects were caused due to the soaring content of chlorophyll in spinach (Mutanen et al. 2011). The consistent incorporation of spinach in the diet is chemopreventive in cancer affirmative subjects.

Some significant understandings into the cancer protecting processes of spinach have established from cell line studies. Various human cancer cell lines were observed to have dose-dependent and time-dependent antiproliferative activity with spinach extracts (Dutta 2015). Spinach leaves constitute major amounts of glycolipids compared to other glycolipid-rich foods. Monogalactosyl diacylglycerol (MGDG) is widely present followed by digalactosyl diacylglycerol (DGDG) and sulfoquinovosyl diacylglycerol (SQDG). Glycolipids from spinach showed antiproliferation action in varied cancer cells acquired from diverse cancer cell lines including gastric cancer (NUGC-3), leukemia (HL-60), lung cancer (A549), cervix cancer (HeLa), B-cell acute lymphoblastoid leukemia (BALL-1), T-cell acute lymphoblastic leukemia (Molt-4), and colon cancer (Colon-26). Glycolipids reduced the activity of markers involved in cell proliferation and terminated the cell progression, triggering apoptosis. SQDG fractions were against cell proliferation by preventing the replicative process of purified DNA polymerase-α (Javadi 2018). In BALB/c mice, spinach glycolipids reduced colon adenocarcinoma tumor growth and sarcoma tumor volume. Glycolipids (20 mg/kg/day) for 2 weeks pretreated animals with Colon-26 cells implantation revealed a 48.9% decline in tumor growth. Additional investigations analyzing the assimilation of spinach glycolipids are required to be established if whole glycolipids, their absorption products, or a blend of both are accountable for the anticancer activities in the gastrointestinal tissues (Roberts and Moreau 2016). It has been proved that spinach-derived glycolipids have antiproliferative potential by preventing DNA replication during tumor growth. Nearly all investigations that analyzed the defensive impacts of spinach on cell proliferation were performed in laboratory rodent and cell lines. The cumulative results recommend that spinach reduces the probability of esophageal, colon, and breast tumors in humans. Nevertheless, there is a crucial requirement for human intervention studies intended at exploring the anticancer potential of spinach and its derivatives.

### 8.4.3 Antiobesity Properties

Improper lifestyle and unhealthy dietary patterns lead to altered BMI and result in obesity. Obesity statistics are on the elevated side with approximately 300 million adults across the world suffering from obesity with a BMI $\geq$ 30 (Swinburn et al. 2011). Various measures related to public health are provided to control the epidemic. Bringing about a change in lifestyle with change in dietary pattern blended with exercise and behavioral therapy are the requisite measures adapted by the medical world to combat serious health issues such as obesity. There is rising concern in the incorporation of nutraceutical ingredients in our daily diet to curb orexigenic signals, which minimizes the intake of calories.

In humans, a patented spinach extract comprising of thylakoids was reported to influence satiety as well as decrease consumption of food in animals: 100 g of spinach-derived thylakoid includes protein, fat, carbohydrate, salt, chlorophyll, lutein, zeaxanthin, β-carotene, vitamin A, vitamin K, vitamin E, folic acid to a level of 23.5 g, 11.9 g, 41.7 g, 3.5 g, 3000 mg, 27.9 mg, 730 μg, 4760 μg, 21 μg, 1313 μg, 6.07 mg, and 166 μg, respectively (Li et al. 2019). Female Sprague-Dawley rats supplemented with fat rich diet supplemented with thylakoids reduced their food intake (Ca. –30 kcal/day) in a 13-day study helped in lowering body weights in comparison with control ones. In another study of 100 days, incorporation with thylakoids helped in inhibiting food consumption, body fat as well as body weight in female apoE-deficient mice (Köhnke et al. 2009a, b). Thylakoids have also been reported to slow down the digestion and fat absorption and promote satiety by stimulating satiety signals (Emek et al. 2011). In healthy humans, it was demonstrated that consumption of diet comprising 25 g, or 50 g spinach thylakoids led to a rise in hormone cholecystokinin after 6 h of food intake.

In another significant study, levels of glucagon like pepetide-1 were reportedly increased (44%) postprandially when women were overnight treated with thylakoid-treated (5 g/day). In addition to cholecystokinin and glucagon-like pepetide-1, the satiety hormone leptin derived from adipose was substantially enhanced after a time period of 6 h subsequent the ingestion of a food including 25 g or 50 g thylakoid. Post intake of a thylakoid supplemented meal, there was a sharp decline in serum levels of ghrelin, a hunger hormone derived from stomach in humans after a period of 2 h.

Various studies have acknowledged the potential of the satiety hormones, leading to a sharp decline in appetite. In a pivotal work, thylakoid incorporation (3.7 g or 7.4 g) in a meal led to inhibition in postprandial hunger and eating tendency in healthy overweight women. Thylakoid incorporation was also pronounced on anthropometric parameters of body composition in overweight women in single-blinded intervention study, which was carried for 12 weeks. It was concluded from this study that there was a significant reduction in body weight of subjects, which were fed on 5 g thylakoids on daily basis as compared to the placebo group. There was no major change in parameters such as fat-free mass, body fat, and circumference of waist with spinach administration (Montelius et al. 2013). Hence, it can be concluded that the supplementation of diet with spinach-derived thylakoids was reported to inhibit interim hunger, intake of calories, and gain in body weight in healthy population via the alteration of cholecystokinin and glucagon-like pepetide-1 and ghrelin secretions.

### 8.4.4 Hypoglycemic Activity

Hyperglycemia is highly predominant worldwide and is recognized as one of the clinical indications of metabolic disorder as well as a prime factor to develop type-2 diabetes. These are considered as the alarming indications, which necessitated the need for adopting innovative nutritional and therapeutic methodologies to monitor glycemia and reduce insulin resistance.

Insulin sensitivity has been also reported to be improved by the consumption of spinach and derived compounds out of it. Various cell culture experiments have proved the insulin-sensitizing mechanism of extracts isolated from spinach (Amirinejad et al. 2019). Effects of raw spinach either in juice form or ethanolic extracts on the variation of 3 T3-L1 preadipocytes were studied in a significant study. It was analyzed that spinach juice and ethanolic extract were able to induce 3 T3-L1 cell differentiation in the presence as well as absence of insulin. In in vitro assays it was also found that spinach as juice as well as ethanolic extract inhibited the assimilation of disaccharides (−19.6%) by intestinal α-glucosidase.

Several animal studies have been reported so far regarding the hypoglycemic potential of spinach-derived composites. In one of the study, Wistar rats administered with alloxan monohydrate in order to abolish β-cells from pancreas and roots insulin deficiency followed by administering daily dosage of 70% ethanolic extract of spinach (100 mg/kg body weight) for 12 successive days led to a noticeable reduction of plasma glucose levels (152 mg/dl). In crossbred pigs supplied with high-fat diet, spinach-derived thylakoid (0.5 g/kg body weight) had the potential to curb blood sugar level to a considerable extent. In an extended investigation, when Sprague-Dawley rats were supplemented with spinach-derived thylakoid for 10 days, plasma levels of insulin dropped in a 2-hour OGTT in comparison to control food lacking thylakoid.

In the medical trial, thylakoids were reported to modulate the postprandial insulin response in healthy subjects. People who were fed with a food containing 25 g or

50 g of thylakoids observed a significant reduction in insulin levels despite the fact that the test meal had higher protein and carbohydrate than control. Decrease in the insulin response in the form of reduction in glucose uptake was reported, since thylakoids reduced the transport of methyl-glucose throughout the intestinal brush border line of rats in vitro by affecting intestinal permeability by attaching to it. In case of obese people, ingestion of a meal including 5 g of thylakoids resulted in significant hike in postprandial plasma glucose concentrations in a time period of 2 h as compared to the placebo-containing meal (Singh et al. 2018a, b). Intake of 5 g of thylakoids before the consumption of a test meal led to lowering of postprandial plasma glucose and insulin levels at 15 minutes followed by slowly lowering of insulin concentrations after a time period of 4 h (Stenblom et al. 2015). To conclude, thylakoids can be utilized as a great tool in regulating postprandial glycemia and insulinemia by inhibiting glucose absorption and decreasing insulin production.

### 8.4.5 Lipid-Lowering Properties

Hypertriglyceridemia in clinical terms can be defined as the condition when blood triglyceride levels go beyond 150 mg/dL, resulting in ailments such as pancreatitis, liver disease, and cardiovascular diseases as well. It is predominant in developed countries, including the United Kingdom, France, South Korea, and the United States to a level of 27.5%, 27%, 25%, and 24%, respectively, but it is also considered as a public health concern in India (47%) (Selçuk 2020). Hypertriglyceridemia can be corrected by weight management accompanied with increased physical activity, nutritional supplementation with fish oil or niacin, and medication intervention as well. Spinach especially spinach thylakoids and its extracts as well can be a great source of alternate choices to these measures. Thylakoid membranes derived from leaves of spinach are a great source of lowering down blood lipids.

Consumption of a meal comprising thylakoids (50 g) reduced serum free fatty acids postprandially than the subjects without consumption of spinach thylakoid. This is well in line with the findings that thylakoid-rich diets decreased serum triglycerides and free fatty acids significantly in both Sprague-Dawley rats and apoE-deficient mice (Köhnke et al. 2009a, b). In a rodent study, there was a reduction in lipid levels with the consumption of daily dose of 70% ethanolic spinach extract (100 mg/kg). Rats treated with spinach extract were reported a reduction in serum triglycerides. It was able to stabilize plasma triglycerides to a level of 83 mg/dL in nondiabetic rats than the diabetic ones. Some of the animal studies have shown the efficiency of spinach-derived thylakoids and phytochemicals in diminishing blood triglycerides (Roberts and Moreau 2016). However, less study has been devoted to investigate the potential of cooked and raw spinach on post-prandial blood triglyceride level. Due to less literature available, the impacts of spinach and its components on blood lipids needs more exploration.

## 8.5 Conclusion

Spinach (*Spinacia oleracea* L.) is a leafy vegetable hailing from goosefoot family. Spinach is known to represent several antioxidative, antiproliferative, anti-inflammatory, and hepatoprotective effects. It has also been acknowledged to exhibit flavonoids, carotenoids, and phenolic compounds as well. Various common chronic illnesses find their causative agents in the form of free radical and inflammatory markers, and spinach has been known to play a role in the eradication of these ailments. Consumption of spinach strengthens the antioxidant defense mechanism. Spinach could be a great source of therapeutically effective extracts. A high level of research is conducted in order to emphasize on the therapeutic uses of spinach leaves. Prospective intervention investigations should address various functional properties to inform the best knowledge derived from clinical experience of spinach as well as its bioactives.

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# Bitter Gourd

9

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**Abstract**

*Momordica charantia* (bitter gourd) is utilized as traditional medicinal plant and food in Indo-China and Southeast Asia. This nutrient plant-based food contains abundant of bioactive components such as polypeptide, minerals vitamins, alkaloids, flavonoids, isoflavones, terpenes, anthroquinones, and glucosinolates. In the present study, physicochemical properties, nutritional values, and health promoting phytochemicals, as well as value added products of bitter gourd are described. Majority of the bioactive compounds in bitter gourd confer bitter taste. A large number of value-added products can be prepared from bitter gourd such as bitter gourd juice, slices, pickle, dried rings, and chips. These valued products in addition to being healthy are more palatable than raw fruit, thus increasing consumption of this bitter fruit. Hence, besides having the health-enhancing properties, it might be considered proficient option in value-added foodstuffs.

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**Keywords**

*Momordica charantia* · Antioxidants · Value addition · Health benefits · Nutraceuticals

## 9.1 Introduction

Bitter gourd or *Momordica charantia* is originated from the Latin word "momordica," meaning "to bite," refers to the grooved ends of its seed that seems like it has been chewed. Bitter gourd as bitter squash, wild cucumber (Eng), bitter apple, bitter melon, bitter gourd, balsam-pear, paria, pare (Indonesian), margose (French), Balsambirne (German), balsamito (Spanish), peria (Malay), concombre (African), and with many more similar names is a subtropical and tropical vine of the family Cucurbitaceae, extensively grown-up in Africa, Asia, also can be found in South America and the Caribbean (Krawinkel and Keding 2006) for its edible fruit. Bitter gourd is of previous world origin and is indigenous of tropical Asia, predominantly in the Indo Burma region. In India, common names are Hagala Kayi in Kannada; Karla in Marathi; Beet, Kakara kaya in Telugu; Pavakai in Tamil; Pavakka in Malayalam, Karela in Hindi, Gujarati, and Punjabi, and Karela in Assamese. The genus *Momordica* have12 species in Asia and Australia plus 47 species in Africa, and, interestingly, bitter gourd is not an Asian origin by a three genome phylogeny but is of African origin (Schaefer and Renner 2010). Bitter gourd in India is an essential vegetable in states, mainly in Karnataka, Tamil Nadu, Maharashtra, Uttar Pradesh, and Kerala.

Bitter gourd is a nutritious and healthy food having a typical bitter flavor, and is broadly subjugated in folklore drug (Fang and Ng 2011). Bitter gourds have been linked with antidiabetic, anticancer, antimicrobial, and anti-inflammatory characteristics. In Ayurveda, the fruit is said to have tonic, stomachic, antibilious, stimulant, alterative, emetic, and laxative properties. Several countries particularly in tropics it is an important vegetable crop. When bitter gourd is compared to other cucurbits, it has fairly elevated nutritional value, in respects of vitamin C and iron contents. Although the major use of bitter gourd is in folk medicine and vegetable crop, but it is also cultivated as a decoration due to its showy flowers (Janick and Paull 2008). It possesses a plain genome having $2n = 22$ chromosomes with a genome size of about 339 Mb. Bitter gourd is mostly monoecious in nature whose pistillate and staminate flowers are produced on separate nodes. Every portion of this plant, mostly the seeds and the fruits, holds further 60 phytomedicines active next to more than 30 illnesses, as well as diabetes and cancer.

In India to which bitter gourd belongs is genus *Momordica* having four species namely *M. charantia* (cultivated bitter gourd), *M. balsamina* (fruits that are not mature are used as vegetable or picked), *M. charantia* var. *muricata* (extremely small and bitter-fruited wild bitter gourd), *M. cochinchinens* is (sweet gourd of Assam) and *M. dioica*. Generally, bitter gourd fruits are 1.0- to 5.9-inch-wide and 1.0- to 9.8-inch-long with oblong, round, oval, and club in shape, and its color varies from dark green to white. Its size and shape varies with the different varieties (Kumar et al. 2016). The bitter gourd fruit takes 45–80 days to get mature, and the harvesting starts from 60 days of planting and it is continued up to 150 days (Kumar et al. 2016). Diverse kinds of bitter gourds are available in around the world. India long green, India long white, and Hybrid India baby are available in India, whereas Japan Green Spindle, Green Lover, and Hong Kong Green are famous in Japan, China, and Hong Kong, respectively. In Bangladesh, mainly two varieties are found: large size is called Korolla and small size is locally called Ucche (Alam et al. 2015).

### 9.1.1 Hierarchy Classification of Bitter Gourd

Species: *Momordica charantia.*
Genus: Momordica.
Family: Cucurbitaceae.
Order: Violales.
Class: Dicotyledonae.
Subphylum: Angiospermae.
Phylum: Spermatophyta.
Kingdom: Plantae.
Domain: Eukaryota.

### 9.1.2 Nutritional Profile of Bitter Gourd

Consumption of vegetables has amplified due to their elevated percentage of bioactive components such as ascorbic acid, phenolic acids, carotenoids, flavonoids, proteins, minerals, and dietary fibers while insufficient source of sugar (Cefalu et al. 2008; Cousense 2007). Among a variety of vegetables, bitter gourd is one of most nutritionally rich and has plentiful medicinal properties around the world. The quality and quantity of bioactive compound present in bitter gourd could possibly be dependent on various factors such as harvest time, temperature, state of maturity, and postharvest storage, as well as its size, shape, and color (Singh et al. 2014). Nutritional profile of bitter gourd is specified in Table 9.1. The bitter gourd fruit is perishable and has storage life of only 4 days at ambient conditions. However, it can be preserved for more than 3–4 weeks in cold storage at 0–70 °C. Fresh cut bitter gourds have only 4 days shelf life when stored at 20 °C. The fruits, seeds, leaves, vines and roots of bitter gourd are utilized as food and remedy for various types of diseases (Islam et al. 2011). It is a vital source of essential amino acids, niacin, vitamin C, carotenoids, vitamin A, folic acid, thiamin, riboflavin, and minerals and has a significant role in human diet to maintain sound health. The seeds of bitter gourd are also loaded with protein and oil (Ali et al. 2008). It is an excellent source of antioxidants such as catechin, chlorogenic acid, and gallic (Budrat and Shotipruk 2009) and saponin compounds (Tan et al. 2014). Pericarp and seeds of bitter gourd could be used as sources of different antioxidant agents (Horax et al. 2010). Habicht

**Table 9.1** Nutritional Parameters of Bitter Gourd

| Parameters | Amount |
|---|---|
| Moisture (%) | 93.8 |
| Ash (%) | 0.8 |
| Protein (g) | 0.90 |
| Fat (g) | 0.1 |
| Carbohydrate (g) | 0.20 |
| Dietary fiber (g) | 3.30 |
| SDF (%dry basis) | 14.4 |
| IDF (%dry basis) | 30.2 |
| Organic acids (g) | 0.11 |
| TSS(*brix) | 3.2 |
| Acidity (%) | 0.03 |
| Reducing sugars (%) | 2.5 |
| Total sugars (%) | 2.8 |
| Chlorophyll (mg/L) | 10.9 |
| Vitamin C (mg) | 50.0 |
| Riboflavin (mg) | 0.03 |
| Thiamin (mg) | 0.05 |
| Vitamin A (mg) | 0.04 |
| Niacin (mg) | 0.40 |
| Phosphorus (mg/100 g) | 69.0 |
| Calcium | 22.0 |
| Potassium | 26.0 |
| Magnesium | 16.0 |
| Iron | 0.9 |
| Sodium | 3.0 |
| Zinc | 0.1 |

(Source: Horax et al. 2010; Islam et al. 2011; Satkar et al. 2013)

et al. (2011) reported total fat content of whole fruit from 2.9% to 6.4% of dry matter. Bitter gourd also contains high number of vitamins B1, B2, B3, and B9 and vitamin A (Joseph and Jini 2013). Bitter gourd vegetables also hold diverse kinds of amino acids such as glutamine, asparagines, glycine, lysine, alanine, leucine, valine, arginine, proline, serine, isoleucine, phenylalanine, tryptophan, histidine, threonine, and methionine (Islam et al. 2011).

## 9.2 Value-Added Products from Bitter Gourd

Bitter gourd postharvest losses are about 25%. During transportation, mechanical damage and ripening are the main reasons for this huge loss. Also because of the watery nature of fruit, the damage by transportation is extremely high. Polysack bags that are used to pack bitter gourds can cause severe damage to the fruit. Postharvest losses could be reduced to a larger extent if the fruits are carefully transported. This perishable fruit could be stored at room temperature for about 4–6 days if at immature stage they are harvested. Moreover, by storing those at 13 °C, the shelf life can also be prolonged.

Bitter gourd value addition could be done by many ways. For example, for domestic purposes, thin slices are dehydrated, and this technology is adopted in a small scale. Bitter gourds in the shape of rings and cubes may be used for different curry preparations. Bitter gourd tea is made by Brown Bitter gourd. The chief function of bitter gourd dehydration is to prolong the storage life and minimize bulk storage, packaging, and transportation. An improved quality of product could be prepared if driers are used for dehydration. Bhattacharjee et al. (2016) reported the dehydration and rehydration properties of bitter gourd fruits. Alteration in drying temperatures and blanching methods were involved, and it was concluded that, among the temperatures and blanching methods, better dehydration and rehydration characters were reported in samples dried at 60 °C and blanched in water for 2 minutes. Additionally, bitter gourd fruits can be canned (Krawinkel and Keding 2006). This vegetable is one of nature's plentiful gifts and is considered an undesirable vegetable by most of the consumers due to its unacceptable bitterness and unpleasant taste, as it has a bitter component called momordicin. Snee et al. (2011) performed a pilot study that was conducted in Hawaii. Their study reported that incorporation of bitter foods in regularly utilized food dishes could shield bitter melon's bitter taste. For example, the bitterness of bitter melon is shielded by tomato-based recipes having sour flavor and was liked by most participants.

Usually bitter gourds are very much consumed as fresh or in different recipes such as soups, salads, stir fried, deep fried, boiled, steamed, microwaved, juiced, pickled, snacks, curries, bakery products, stuffed products of meat, and oven dried to drink as tea. Naturopaths recommend fresh bitter gourd juice. In many Ayurvedic medicines, stem and roots of wild bitter gourd are used. The immature fruits are used in a wide range of culinary preparations. It could be deep fried, fried, juiced, boiled, pickled, and dehydrated and also dried that can be used to drink like tea (Myojin et al. 2008). The fruit has immense potential as a food source in both industrialized and developing nations. Various processing technologies produce widely acceptable products, extending shelf life and availability of all the year round and adding value of the raw products.

Generally, bitter gourd juices are unacceptable to various communities due to its tremendous bitter taste. For this reason, it is needed to develop a suitable formulation, processing, and storage using bitter gourd-fortified juice and thus making it palatable and acceptable to consumers. Additionally, the regular vegetable could be available for the customers throughout the year also in the shape of beverage. A common method of preparation of bitter gourd beverage is that fresh bitter gourds are rinsed carefully and peeled from the top. The pulp of this vegetable is extracted in an extractor juicer/pulper/blender/filter press and then strained. The pasteurization of juice is done at 83 °C for 3 min, and vitamin C at 0.15% is supplemented. This regular vegetable could be prepared and make available for the customers in off-seasons also in the form of beverage. Shelf life could be extended by adding chemical preservatives mainly potassium metabisulfite (KMS). Kaur and Aggarwal evaluated the influence of various chemical additives specifically sodium benzoate, (KMS) and their mixture, on the phytochemical, physicochemical factors, and antioxidant activity of the beverage made from the bitter gourd. Among all preservatives added, KMS uphold the highest nutrient stability. Blending of different ratios of lemon and bitter gourd are used to prepare ready-to-use functional beverages. The sensory properties and physicochemical compounds of blended beverage were estimated for 60 days at 15 days of storage interval. The study concluded that bitter gourd–lemon functional drink made at 50:150 was mainly acceptable for lowest alteration in total soluble solids, acidity, and pH (Singh and Gaikwad 2012). On the other hand, different concentration of bitter gourd juice, sugar, and citric acid was used to prepare ready to serve bitter gourd beverages (Satkar et al. 2013). These research groups reported that ready to serve bitter gourd beverage could be made using the levels of juice 12.5%, sugar 15 g, water 76 mL for 100 mL of beverage, and citric acid 0.29 g, and kept refrigerated ($5 \pm 1$ °C) up to 3 months without changing the chemical and sensory qualities. Bitter gourd juice has been known as nutraceutical on the basis of presence of some bioactive components. The juices of other fruit like lemon, amla, etc. can be added to bitter gourd juice to enhance the nutritional value, as well as palatability and overall wholesomeness.

### 9.2.1 Fried Bitter Gourd Chips

The most significant attributes of fried food are texture, appearance, and flavor. In the United States, chips are most popularly consumed snacks and contains oil percentage of about 35.3%–44.5% w.b. that provides the distinctive quality attribute making the chips more advantageous (Garayo and Moreira 2002). Bitter gourd chips are well known for their taste and texture. Borse and Mishra 2014 studied the physicochemical characteristics of bitter gourd chips. Different frying temperatures were involved, and their effect was studied. Furthermore, bitterness was masked off by treating the bitter gourd slices with 1% turmeric and 2% salt and then allowed to rest for 30 min. Corn flour increased the crispiness of chips and the nutritional quality of bitter gourd chips. Evaluation of different physicochemical and sensory parameters such as taste, texture, flavor, and color was found satisfactory when bitter gourd chips were fried at 160 °C. It was concluded that given treatments decreased the bitterness from bitter gourd and thus their utilization was capitalized. Bitter gourd chips should be packed in the low-density polyethylene bags (LDPE) and then sealed using sealing machine and labeled properly. Packed bitter gourd chips should be kept in the dry or cool place.

### 9.2.2 Bitter Gourd Slices

Dehydrated bitter gourd slices, rings, and cubes are hold good import and export market potential. Preetha et al. (1943) carried out an experiment to enhance the bitter gourd slices shelf life by modified atmospheric packaging. Polypropylene (PP) and low-density polyethylene (LDPE) films were preferred as a packaging material because of their low permeability to $O_2$. The results showed that bitter gourd slices can be kept for 15 days at 80 °C without deteriorating its nutritional quality when kept in modified atmosphere packaging with low-density polyethylene bag. Various modern drying methods such as infrared (IR)-dependent hybrid drying and dry blanching concerning IR-hot air were used as a substitute to hot air drying and wet blanching (water and steam). The hybrid drying and infrared (IR)-assisted blanching caused reduction in processing time with greater nutrient retention and thus have immense industrial potential to decrease processing time and also energy, and further produces the product of better quality. Silva et al. developed the fermented bitter gourd slices (3% dry salts and 3% saturated brine solution, and 3% dry salts with 1% saturated brine solution in refrigerated condition for 4 weeks), and physiochemical and sensory parameters were assessed. Results showed that bitter gourd slices treated with 3% dry salt was highly acceptable as fermented ready-to-eat vegetables, and maximum overall acceptability also increased during storage period.

Thus, value addition of bitter gourd not only improves the economic status of people, especially women and farmers, but also aids in fighting against several chronic diseases.

## 9.3 Antioxidant Evaluation of Bitter Gourd Fruit

Recognizing and searching safe natural antioxidants, especially of plant origin, has been particularly improved in current years. Physiological function of natural foods could be attributed to the antioxidative capacity of their bioactive components. The antioxidant property of fruit is well associated with the amount of oxygen radical scavengers, such as phenolic components (Giampieri et al. 2012). Different assays are used to determine the antioxidant potential of natural products such as 2,2-azino-bis (3-ethyl-benz-thiazoline-6-sulfonicacid) (ABTS), ferric reducing antioxidant powder (FRAP), peroxyl radical scavenging capacity (PSC), DPPH (2, 2-diphenyl-1-picrylhydrazil), oxygen radical absorbance capacity (ORAC), linoleic acid bleaching, and β-carotene. Many studies have previously reported that bitter gourd is an antioxidant-rich vegetable (Horax et al. 2005; Wu and Ng 2008; Kubola and Siriamornpun 2008). Due to higher content of phenolics in bitter gourd, it is said to be the richest source of antioxidants (Horax et al. 2005). However, the quantity and kinds of phenolics might alter with maturity and growth of Bitter gourd and collectively these alterations can influence the antioxidant activity of the extracted phenolics. Commonly known solvents used for extraction of phenolics are ethyl acetate, acetone, methanol, ethanol, propanol, water, dimethyl formamide, and their combination (Antolovich et al. 2000).

Lee et al. (2017) investigated the carotenoid and phenolic acid compounds of bitter melon to estimate its antioxidant activity. The concentration of phenolic components such as gallic acid, catechin, and chlorogenic acid enhanced with maturation; meanwhile, the concentration of caffeic acid, ferulic acid, and p-coumaric acid reduced with maturation. Furthermore, free radical scavenging behavior improved with growing maturation. They concluded that antioxidants are naturally present in abundant amount in bitter melon and could have possible health promoting benefits as a value-added ingredient or functional food. In vitro antioxidant evaluation (namely DPPH, FRAP, hydroxyl radical-scavenging activity, β-carotene-linoleate bleaching assay, and entire antioxidant ability) of the aqueous leaf extract, fruit, and stem was investigated. The leaf extract illustrated the maximum value of ferric reducing power and DPPH radical-scavenging activity, as the extract of green fruit illustrated the maximum values of antioxidant activity, depend on total antioxidant activity, hydroxyl radical-scavenging activity, and β-carotene-linoleate bleaching assay. The major phenolic components were gallic acid, caffeic acid, as well as catechin (Kubola and Siriamornpun 2008). A study on antioxidant characteristics of bitter gourd after removing seeds and pith and entire fruits of two varieties (var. maxima and var. minima) in Malaysia was conducted, and the effect of processing conditions such as boiling and blanching was investigated. DPPH and FRAP assays were used for antioxidant evaluation. It was observed that boiling and blanching of fruits devoid of pith and seeds of *M. charantia* var. minima and var. maxima prompted alteration in the antioxidant activity unusually. The radical scavenging activity of the fruits devoid of pith and seeds of *M. charantia* var. minima and var. maxima improved due to boiling and blanching although their ferrous ion chelating activity became unnoticeable. There was no apparent relationship between the antioxidant activities and antioxidant content (Choo et al. 2014). The antioxidant capacity of bitter gourd polysaccharides is considerably influenced by cultivars (Li et al. 2010). The chemical structure of isolated polysaccharides was analyzed by FTIR (Fourier-transform infrared spectroscopy) and GC (gas chromatogram). Superoxide radical-scavenging activity and hydroxyl radical–scavenging activity were used as antioxidant assays. D-galactose (Gal), D-glucose (Glu) and L-arabinose (Ara) were the main polysaccharides with antioxidant activities (Li et al. 2010). The anthocyanin (main flavonoid group that is responsible for cyanic colors) content is also present in abundant amount in bitter gourd. Total anthocyanins of *M. charantia* fruits could be used as easy available source of antioxidants as a potential food supplement or in medical and pharmaceutical industries (Aytaç Güdr 2016). Water can be suitable solvent to extract phenolic components and their related antioxidant activities from freeze-dried bitter melon when compared with other organic solvents such as acetone, methanol, 80% ethanol, and butanol (Tan et al. 2014).

This vegetable has conjugated α-linolenic acids and tocopherols (mostly γ-tocopherol) and phytosterols (primarily β-sitosterol) in their seed oil. The α-linolenic acids have been related with several effects that are valuable to health such as anti-inflammatory and antioxidant characteristics. Hence, seed oil of bitter gourd that is a by-product of extraction and processing could be a vital and excellent source of polyunsaturated fatty acids (Yoshime et al. 2018). Aqueous extract of seeds of two varieties, specifically a hybrid and country variety of bitter gourd (MCSEt2 and MCSEt1), has antioxidant activity in streptozotocin (STZ)-induced diabetic rats. It was observed that upon incorporation of seed extract of bitter gourd, there was a fast-defensive effect against lipid peroxidation by scavenging of free radicals (Sathishsekar and Subramanian 2005).

## 9.4 Health Benefits of Bitter Gourd

Public attentiveness of the perceived dietary antioxidants health benefits has improved the requirement for vegetable and fruit products with known and enhanced antioxidant quality and has led to new chances for the horticulture industry to enhance vegetable and fruit quality by improving antioxidant percentage. Medicinal importance of bitter gourd is attributed to its elevated antioxidant characteristics owing in part to flavonoids, phenols, terpenoids, etc. In the current day's situation, also, the medicinal properties of bitter gourd are widespread and that is the reason why they are grown everywhere. Preclinical, clinical, and epidemiological studies have confirmed a close correlation within dietary habits, such as bitter gourd ingestion and disease occurrence. Bitter gourd is said as one of the greatest disease-protective food based on its possible and diversified properties (Amagase 2006). Some of important health benefits of bitter gourd are described below.

### 9.4.1 Antihyperglycemic Activity

Diabetes mellitus (DM) has turned out to be the world's third most fatal metabolic disorder attributed to hyperglycemia (Wang et al. 2013). This chronic disorder is described by many consequences and causes. It is forecasted that adults who are expected to suffer from diabetes mellitus by the year 2020 will be around 300 million (Jeszka-Skowron et al. 2014). Although a broad spectrum of allopathic antidiabetics is currently present in market, but these drugs have ample side effects. The treatment of diabetes using herbal methods has relatively less or no side effects and is locally present. Medicinal plants are the "backbone" of conventional medicine and is considered to be the better source of life for people because of its immense therapeutic characteristics and being absolutely natural (Asija and Charanjeet 2016).

Bitter gourd has been broadly reported and used because of its hypoglycemic effects in many studies (Hasan and Khaton 2012). Saponins, glycosides, triterpenes, alkaloids, polysaccharides, proteins, charantin, steroids, a polypeptide-p, 3-O-glucuronide, and oleanolic acid and 3-O-monodesmoside are the important compounds found in bitter gourd with hypoglycemic activity. A number of preclinical reports have studied the hypoglycemic and antidiabetic effects of bitter gourd by several postulated mechanisms, though, with human subjects clinical trial data are flawed and limited by deprived study design and little statistical power (Joseph and Jini 2013). Polypeptide k and oil separated from bitter gourd have in vitro α-amylase (53.55%) and α-glucosidase (79.18%) inhibition activity. Jointly, the in vitro assay of this study powerfully suggested that both seed oil and polypeptide k from bitter gourd can be a potential source of hypoglycemic agents (Ahmad et al. 2012). It is essential to recognize, characterize, and isolate the bioactive components and biochemical mechanism accountable for these effects in type II diabetes. An oral dosage of 150 mg/kg body weight on daily basis for 5 weeks, a 4-week-old male db/db mice were orally administered with bitter gourd. It was studied that there was a considerable decline in weight gain in every bitter gourd–treated groups. Glycated Hb levels were the highest in the control mice than the bitter gourd–treated mice (Klomann et al. 2010). STZ-induced male Wister rats were orally administered bitter gourd juice, which were diabetic (10 mL/kg/day as prophylaxis for 14 days before initiation of diabetes, then 21 days' treatment or after induction of diabetes treatment given for 21 days). After sacrificing of rats, histopathological inspection of pancreas was carried out. It was observed that bitter gourd juice resulted in considerable drop of serum glucose (135.99 ± 6.27 and 149.79 ± 1.90 vs. 253.40 ± 8.18) for prophylaxis and treatment correspondingly. Insulin (lIU/mL) level in diabetic rats was 2.39 ± 0.27, while that on bitter gourd–treated rats was 3.28 ± 0.08. In the end, this report confirmed that bitter gourd juice exhibited hypolipidemic, hypoglycemic, and great antioxidant characteristics when orally injected as prophylaxis or treatment to STZ diabetic rats (Mahmoud, et al. 2017). Bitter gourd could also destroy carbohydrate enzyme activity such as phosphofructokinase, glucokinase substrate glucose-6-phosphate, and hexokinase after treatment with bitter gourd in liver of diabetic mice (Rathi et al. 2002). Charantin, a hypoglycemic compound comprising of a mixture of (1:1) stigmasteryl glucoside (C35H58O6), sitosteryl glucoside (C35H60O6), and belongs to steroidal saponins. This compound when taken either intravenously or orally in rabbits exhibits potential hypoglycemic effect (Lolitkar 1966). This hypoglycemic loaded extract is a possible compound for raising insulin-sensitivity in type II diabetic patients (Wang et al. 2014).

Bitter gourd seeds contain vicine and pyrimidine nucleoside, which are reported to cause hypoglycemia in rats, when incorporated intraperitoneally (Dutta et al. 1981). Eight cucurbitane-type glycosides were isolated recently by bioactivity-guided fractionation showing hypoglycemic effect in vitro (Zhang et al. 2014).

### 9.4.2 Hypolipemic Activity

Hyperlipidemia is a disease of lipid metabolism caused by abnormal elevation in diverse lipoprotein and lipid fractions in plasma. It is identified by surplus fatty substances and cholesterol in the blood resulting a risk factor for cardiovascular disease. Hyperlipidemia is described as raise in low-density lipoproteins (LDL) and very-low-density lipoproteins (VLDL), total triglycerides (TG), high-density lipoprotein (HDL), and serum total cholesterol (TC) that are accountable for various health problems such as stroke, heart attack, atherosclerosis, coronary artery syndrome, pancreatitis, and myocardial infarction (Asija and Charanjeet 2016). Various experimental researches recommend that bitter gourd enhances metabolism of lipid in animal models of diabetes and dyslipidemia. Bitter gourd extract has been studied for the effects on metabolism of lipid with a one-month treatment time in Japanese adults (both men and women). The blood pressure, body weight, amount of low-density lipoprotein cholesterol (LDL-C), and other blood parameters (total cholesterol, weight, systolic pressure, high-density lipoprotein cholesterol, diastolic pressure, body mass index, blood glucose, or triglycerides) of every matter were calculated after and before the study time. Among all the parameters, bitter melon extracts could efficiently lesser LDL-C levels in humans and show possible therapeutic importance to manage of dyslipidemic conditions (Kinoshita and Ogata 2018).

Bitter gourd fruit juice has hypolipidemic and also hypoglycemic effects in the STZ-induced diabetic rat. In one of the studies, there was a major reduction in triglycerides, phospholipids, and plasma nonesterified cholesterol in STZ-induced diabetic rats, escorted by a decline in HDL cholesterol in STZ-induced diabetic male Wistar rats when given bitter gourd juice (Ahemed 2001). TG and TC were significantly reduced in albino rats when given high-fat diet (HFD) supplemented by aqueous bitter gourd fruit extract (100 mg/kg) (Sethi and Dahiya 2019). Noguchi et al. (2001) studied the effect of bitter gourd oil (BGO) effects on the liver and blood lipids of rats. They reported that dietary BGO has strong influence on the fatty acid composition of liver lipids.

### 9.4.3 Antimicrobial Activity

There are widespread researches that are carried out on antimicrobial characteristics of medicinal plants around the world. As per the World Health Organization (WHO), 80% of the world's population utilizes extract or their active components as folk drug in traditional therapies. Medicines from natural origin help significantly in the treatment and prevention of human ailments. Between 1981 and 2002, around 61% of new medicines formed were depend on natural products and were conquering, mainly in the field of cancer and infectious disease (Cragg and Newman 2005).

Methanolic and petroleum ether crude extracts of leaves and fruits of bitter gourd showed potential antimicrobial activity by means of the disk diffusion technique on four types of microorganisms (*Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus*, and *Candida albicans*) and four clinical strains of *Proteus vulgaris*, *Klebsiellapneumoniae*, *Salmonellatyphi*, and *Cryptococcus neoformans*. Among the two extracts, methanolic extract showed widest antimicrobial spectrum by hindering majority (75%) of the tested microorganisms. Also, their study reported that bitter gourd fruit extracts exhibited elevated antimicrobial activity than leaf extract (Mwambete 2009).

An extract of the whole plant was revealed to possess an antiprotozoal activity against *Entamoeba histolytica*. The juice and fruit have illustrated the similar kind of antibacterial characteristics (Gupta et al. 2010), and in one more study, fruit extract illustrated activity against the *Helicobacter pylori* which are stomach ulcer-causing bacteria. Bitter gourd has also been familiar with in vitro antiviral property against several viruses, as well as HIV, Epstein-Barr, and herpes viruses.

Bitter gourd oral ingestion can counterbalance the detrimental impact of anti-HIV drugs, if the studies of test tube could be translated into clinical implementations. In one preliminary clinical trial, an enema form of a bitter gourd extract exhibited some advantages in people affected with HIV (Zhang 1992).

Leaves of bitter gourd also show strong antimicrobial activity against some microorganisms. Aqueous and methanolic bitter gourd leaves extracts possess antimicrobial activity against *Escherichia coli*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, and *Klebsiella pneumoniae* and by using stokes disc diffusion and well diffusion methods (Leelaprakash et al. 2011).

### 9.4.4 Some Miscellaneous Health Benefits of Bitter Gourd

Bitter gourd extract has therapeutic agent for tissue regeneration. It possesses wound-healing properties and stimulated the proliferation of dermal fibroblasts of human (Tan et al. 2016). In Brazil, bitter gourd's traditional medicine is used for treating certain diseases such as menstrual problems, leucorrhea, tumors, rheumatism, wounds, malaria, fevers, colic, inflammation, worms, and can be used as an aphrodisiac and abortions inducer (Maiti et al. 2012). It is also utilized for skin diseases (itchy rashes, scabies eczema), hemorrhoids, vaginitis, and leprosy. In Mexico, for controlling dysentery whole plant is used. In Peruvian herbal medicine, the aerial parts or leaf of the plant helps to treat every type of inflammation, malaria, and measles. In Nicaragua, the leaf normally is employed for treating aliments such as diabetes, skin complaints, coughs, fevers, colds, headaches, menstrual disorders, aches, stomach pain, malaria, pains, and infections, as an aid in hypertension and childbirth. Principally, studies have shown positive association between eating bitter gourd and avoidance or reduction in tumor growth in prostate, cervical, and breast cancer patients. Bitter gourd ethanol seed extracts are also reported to possess potent male antifertility properties when fed to guinea pigs and dogs. Traditionally, equal proportion of bitter gourd leaves paste is mixed with the Tulsi leaves paste. This can be taken with honey every morning as a prevention and treatment for respiratory ailments such as pharyngitis, common cold, and asthma.

## 9.5 Conclusion

Due to diverse chemical constituents in bitter gourd, it could be used as an essential health-promoting functional food and nutraceutical. The study concluded the role and importance of bitter gourd in diverse areas, and from this discussion, it is sufficiently obvious that bitter gourd is a multifunctional natural plant having enormous vitality. Besides its incredible role in various food industries as functional food, it can also be used as nutraceutical in pharmaceutical industries. Therefore, bitter gourd is a multipurpose plant with potential pharmacological properties. Most of its chemical parameters have been explored for treating problems such as bacterial and viral infections, diabetes, pain, stomach problems, as well as life-threatening diseases such as cancer and HIV infections. There are many in vitro and in vivo studies on chemical constituents; however, there are limitation researches on human studies using bitter gourd. Thus, the much more researches are needed on specific diseases using bitter gourds.

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# Tomato (*Solanum Lycopersicon*) 10

Amarjeet Kumar, Varun Kumar, Amir Gull, and Gulzar Ahmad Nayik

**Abstract**

Tomato is the major fruit and vegetable crop produced worldwide. India is the second-largest producer of tomato after China. According to FAOSTAT 2018, India produced18.74 million tons with productivity rate 21.24 ton/Ha. Consumption of tomato fruits is considered as healthy diets that have potential to reduce the risk of cancer, osteoporosis and cardiovascular disease. People who used to eat tomatoes regularly have a reduced risk of increasing cholesterol level, heart disease, blood pressure, cell damage, and blood sugar. Tomato fruit is the rich source of lycopene. Lycopene is a carotenoid that is present in tomatoes, processed tomato products and other fruits. It is one of the most potent antioxidant molecules among dietary carotenoids. Dietary intake of tomatoes and tomato products containing lycopene has been shown to be associated with a decreased risk of chronic diseases, such as cancer and cardiovascular disease. Regular intake of tomato also has many benefits in other many diseases and disorders like counteract acidosis, reduce migraines, boost immunity, natural sunscreen, strengthen bones, treatment of vasodilation, lead toxicity, eye disorder and wound repair.

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**Keywords**

Tomato · Lycopene · Antioxidant · Health benefits · Acidosis · Migraines

## 10.1 Introduction

Kingdom: Plantae
Order: Solanales
Family: Solanaceae
Genus: *Solanum*
Species: *S. lycopersicum*
Binomial name *Solanum lycopersicum* L.

Tomato is a globally cultivated plant for its fleshy fruits and is reported as a protective food because of its nutritive value. It is cultivated widespread around the year. It is the world's second-largest vegetable cultivated after potato, and it tops in the list of canned vegetables. Tomatoes are consumed either directly as raw vegetable or enjoyed in form of processed products like ketchup, sauce, diced, chutney, juice, soup, paste, puree, etc. Tomatoes don't lose any of their nutritional value in the high heat processing, making canned tomatoes and tomato sauce both just as viable and beneficial as fresh tomatoes. The researchers found that tomatoes are the biggest source of dietary lycopene, a powerful antioxidant that, unlike nutrients in most fresh fruits and vegetables, has even greater bioavailability after cooking and processing. Tomatoes also contain other protective mechanisms, such as antithrombotic and anti-inflammatory functions. Research has additionally found a relationship between eating tomatoes and a lower risk of certain cancers as well as other conditions, including cardiovascular disease, osteoporosis, ultraviolet light-induced skin damage and cognitive dysfunction. Tomatoes are widely available, people of all ages and cultures like them, and they are cost-effective and are available in many forms. "Leveraging emerging science about tomatoes and tomato products may be one simple and effective strategy to help individuals increase vegetable intake, leading to improved overall eating patterns, and ultimately, better health. Tomatoes are the most important non-starchy vegetable. Research underscores the relationship between consuming tomatoes and reduced risk of cancer, heart disease, and other conditions," the authors conclude. "The evidence also suggests that consumption of tomatoes should be recommended because of the nutritional benefits and because it may be a simple and effective strategy for increasing overall vegetable intake".

It is a rich source of vitamin A and C and also contains certain minerals and metabolites like iron, phosphorus, folic acid, carotenoids, potassium and glycoalkaloids (Perveen et al. 2015). Tomato has become an important cash and industrial crop in many parts of the world (Ayandiji and Adeniyi 2011) not only because of its economic importance but also because of its nutritional value to human diet (Wilcox et al. 2004). Red ripe tomato is rich in vitamin C (27 mg)

**Table 10.1** Nutritional profile of tomato fruit (nutrient value per 100 g)

| Parameters | Composition |
|---|---|
| Moisture | 94% |
| Protein | 0.9% |
| Fat | 0.2% |
| Carbohydrate | 3.6% |
| Fibre | 0.8% |
| Mineral | 0.5% |
| Calories | 20 kcal |
| Carotene | 351 mg |
| Thiamine | 0.12 mg |
| Riboflavin | 0.06 mg |
| Niacin | 0.4 mg |
| Vitamin A | 833 IU |
| Vitamin C | 27 mg |
| Vitamin E | 0.54 mg |
| Folic acid-free | 14 mg |
| Folic acid-total | 30 mg |

Source: Ayandiji and Adeniyi (2011)

content and carotene (351 mg) Ayandiji and Adeniyi 2011). Matured green tomatoes have shown richness in ascorbic acid (23.4 mg) and potassium content (204 mg), whereas zinc (0.07 mg) and thiamine (0.060 mg) are found in trace amount. Table 10.1 and Table 10.2 show the nutritional value of ripe tomatoes and mature green tomatoes, respectively.

### 10.1.1 History

The Aztecs of Central America cultivated the tomato plant, which they called *xitomatl* at about 700 A.D. Spanish conquistadors named it tomate. Tomato seeds were transported from the Andes to Spain and from there to other European countries around 1520. In Italy, tomatoes were named *pompodoro* or "golden apple" and in France, "pomme d'amour" or apple of love. In 1781, Thomas Jefferson mentioned that tomatoes were grown in Virginia; the use of tomato soups and sauces in the United States began about 1830. Because the tomato plant belongs to the Solanaceae plant family, members of which produce toxic alkaloids such as nicotine, the fruits were assumed to be poisonous, and their consumption was scowled upon. For this reason, most tomato plants were grown as ornaments. The widespread use of tomatoes in the United States as a food began during the second half of the nineteenth century. Current world production is estimated at 24 million tons. Tomatoes are used in many processed foods such as canned and solar-dried tomatoes, juices, ketchup, pastes, purees, salads, sauces and soups. Although the tomato is widely assumed to be a vegetable, it is actually a fruit, often called tomato fruit. Humans consume tomato glycoalkaloids as a part of the diet, so to place the

**Table 10.2** Chemical composition of mature green tomato fruit (100 g fresh weight)

| Parameters | Composition |
|---|---|
| Water (g) | 93 |
| Energy (kcal) | 23 |
| Protein (g) | 1.20 |
| Fat (g) | 0.20 |
| Carbohydrate (g) | 5.10 |
| Total dietary fibre (g) | 1.1 |
| Total sugars (g) | 4 |
| Calcium (mg) | 13 |
| Iron (mg) | 0.51 |
| Magnesium (mg) | 10 |
| Phosphorus (mg) | 28 |
| Potassium (mg) | 204 |
| Sodium (mg) | 13 |
| Zinc (mg) | 0.07 |
| Ascorbic acid (mg) | 23.4 |
| Thiamine (mg) | 0.060 |

Source: Ayandiji and Adeniyi (2011)

following discussion in the proper perspective, we will briefly describe the composition, nutrition and health benefits of tomatoes. Tomatoes contribute antioxidants, carbohydrates, fibre, flavour compounds, minerals, proteins, vitamins, calistegines and glycoalkaloids to the diet (Ravi Mehta 2017).

### 10.1.2 Production of Tomato

Over decades, tomatoes were cultivated only during favourable season; recently tomatoes are grown around the year. Because of its economic importance, area distributed for cultivation is increasing every year. Tomato is an important and popular grown horticultural commodity in the world and by weight ranks third in global production of all horticulture produce behind potatoes and sweet potatoes (Tan et al. 2010). It accounts for about 5.9 million hectares of harvested land area with an estimated production of 170.89 million tonnes. China leads world tomato production with about 52.72 million tons followed by India with 18.74 million tons. Table 10.3 shows the major tomato producing countries in the world for 2016.

India's total tomato production for 2016–2017 was 18,826.99 million tons with Madhya Pradesh leading the states with 3102.00 million tons followed by Karnataka (2138.13 MT) and (Andhra Pradesh 2100.95 MT). Table 10.4 shows the list of tomato-producing states in India. The estimated area and production of tomato are about734.59 and 18,826.99 tons, respectively. India's export of value-added tomato products was around 950.8 tons, which included 41 tons of canned tomato products, 38 tons tomato juice valued at and 595 tons ketchup in the year 2014–2015. This accounts for more than thousand crores to the Indian economy even with least price

**Table 10.3** Major tomato-producing countries in the world (2016–2017)

| Country | Production (Million tons) | Area (Million ha) | Yield (T/Ha) |
|---|---|---|---|
| China | 52.72 | 1.00 | 52.63 |
| India | 18.74 | 0.88 | 21.24 |
| USA | 14.52 | 0.16 | 88.85 |
| Turkey | 11.85 | 0.32 | 37.13 |
| Egypt | 8.29 | 0.21 | 38.73 |
| Iran | 5.97 | 0.16 | 37.54 |
| Spain | 4.89 | 0.05 | 89.29 |
| Brazil | 4.30 | 0.06 | 66.85 |
| Uzbekistan | 2.29 | 0.07 | 35.14 |
| Italy | 5.62 | 0.10 | 54.51 |
| Others | 41.70 | 2.00 | 20.83 |
| Total | 170.89 | 5.90 | 542.74 |

Source: FAOSTAT website (http://faostat3.fao.org/home/E/) accessed on 21st January, 2018

**Table 10.4** State-wise area and production of tomato (2016–2017)

| States | Area (in '000 Ha) | Production (in '000 MT) |
|---|---|---|
| Madhya Pradesh | 100.00 | 3102.00 |
| Karnataka | 63.73 | 2138.13 |
| Andhra Pradesh | 55.50 | 2100.95 |
| Telangana | 53.64 | 1364.93 |
| Gujarat | 46.40 | 1319.11 |
| Odisha | 91.03 | 1311.72 |
| West Bengal | 57.35 | 1233.16 |
| Bihar | 46.26 | 1011.02 |
| Maharashtra | 43.64 | 957.17 |
| Chhattisgarh | 56.63 | 953.16 |
| Tamil Nadu | 38.78 | 840.21 |
| Uttar Pradesh | 20.88 | 826.32 |
| Haryana | 31.49 | 763.74 |
| Himachal Pradesh | 11.08 | 489.96 |
| Assam | 18.18 | 415.41 |
| Total | 734.59 | 18,826.99 |

Source: FAOSTAT website (http://faostat3.fao.org/home/E/) accessed on 21st January, 2018

like three rupees per kilo. This significant achievement in tomato production is possible due to the development of high-yielding varieties/hybrids, breeding for biotic and abiotic stresses, resistance and heterosis breeding. New hybrids are being developed.

### 10.1.3 Botanical Description

In 1753 the Carolus Linnaeus first recognized the tomato in the genus *Solanum*, but in 1754 Miller recognized it in the genus *Lycopersicon*. The recognition by Miller of tomato as *Lycopersicon* was broadly used by majority of botanists and plant breeders, but some authors treat tomato in *Solanum* genus (Peralta 2001). Molecular study data from chloroplast DNA restriction sit and sequence kept the tomato with potato family. Extenuating this treatment on phylogenetic grounds that leads to the assignment or re-assignment of the other species of *Lycopersicon* to *Solanum*. The continual conservation of *Lycopersicon* can only be justified in terms of convenience and the maintenance of the nomenclatural constancy (Peralta and Spooner 2001).

### 10.1.4 Taxonomy

Tomato belongs to the family Solanaceae, which is also known as nightshade family, genus *Solanum*, subfamily Solanoidaeae and tribe Solaneae. The genus includes a variety of cultivated species like *S. lycopersicum Mill* and wild species like *S. peruvianum, S. pimpinellifolium, S. hirsutum, S. glandulosum* and *S. cheeseman.* Recently, taxonomists have changed the name of tomato from *lycospercicum esculentum* to *Solanum lycopersicon.* Tomato is native to Central and South America. It is a very popular and highly versatile food. In tomato the edible part is only fruits since the leaves are reported to contain toxic alkaloids. The cultivated variety of tomato (*Solanum lycopersicon*) is the second most consumed vegetable worldwide after potato and hence well-studied crop in terms of its genetics, genomics and breeding.

The tomato is generally a perennial plant but usually grown as an annual plant. It is reported that tomato plants can reach a height of 3 metres. The stems are weak and often require a staking or support such as a tomato cage of sticks. Branching starts at the base known as monopodial and then becomes sympodial higher up. The tomato leaves are unevenly imparipinnate of 10 to 30 cm long with variously indented or lobed margins. The leaves and the stems are slightly rough and fuzzy, and the inflorescence of tomato bares small yellow flowers having five pointed lobes on the corolla. The fruits of tomatoes are fleshy berries which are green in colour when unripe and then change to deep red colour when ripe due to lycopene formation. The cultivated tomato varieties differ significantly in shape, colour and size. Apart from red fruits, there are also orange, yellow, brown and green colour varieties of fruits. The shape varies from small cherry tomatoes, pear-shaped tomatoes to large irregular-shaped beefy tomatoes; the market value of tomatoes is decided by the shape, size and colour; a wide range of processed items are prepared on industrial scale for consumption and for export using a huge varieties of tomatoes (Parveen et al. 2020).

## 10.2 Antioxidant Properties of Tomato

Antioxidant compounds have received attention from natural product consumers and researchers due to their pharmacological properties. Antioxidants can lower oxidative stress caused by reactive oxygen species (Nordberg and Arnér 2001). There is an increasing interest in natural antioxidant products for use as medicines and food additives (Willcox et al. 2004). Phytochemicals such as polyphenols and carotenoids are important because of their contributions to human health with multiple biological effects such as antioxidant, antimutagenic, anticarcinogenic and cytoprotective activities (Ajila and Prasada Rao 2008). Fruits and vegetables contain biologically active components, which have an important impact on health and disease reduction. In tomato fruit, the main bioactive compounds are carotenoids, phenolics and L-ascorbic acid; these compounds act as antioxidants having a protective effect against various forms of cancer and cardiovascular diseases (Young and Lowe 2001). Tomato is one of the significant parts of the human diet and is also an abundant source of bioactive compounds (Willcox et al. 2004). Studies have shown that high consumption of tomato is correlated with a reduced risk of some types of cancer (FAO/WHO 2009; Van het Hof KH et al. 2000) and heart disease (Omoni and Aluko 2005). These defensive roles have been mainly attributed to the carotenoid compounds. Carotenoid compounds are reported to be mainly responsible for the prevention of these diseases. Numerous epidemiological studies have shown that lycopene intake, amount or serum lycopene, had an inverse association with the risk of prostate, pancreas and possibly stomach cancers (FAO/WHO 2009; Gartner et al. 1997). Lycopene, responsible for the characteristic red colour of ripe tomato and tomato products, has the ability to function as an antioxidant and to quench singlet oxygen in vitro (Alda et al. 2009). Tomatoes also contain the other carotenoids, phytofluen, $\beta$-carotene, neurosporene, lutein and zeaxanthin, which play an important role in the human body's defence system. In addition to this, it is thought that lutein and zeaxanthin mainly prevent age-related macular degeneration and cataracts (Agarwal and Rao 1998).

Reactive oxygen species (ROS) are oxygen-containing molecules that either are or have the potential to generate free radicals. Overproduction of ROS results in a condition known as oxidative stress, which has been linked to both cancer and cardiovascular disease (Halliwell 1994). Carotenoids, including lycopene, can be potent antioxidant molecules and are especially effective at scavenging the ROS singlet oxygen. The carotenoid lycopene is the most effective singlet oxygen scavenger in vitro (Story et al. 2010). This antioxidant activity has been proposed as a mechanism for the potential health benefits of carotenoids (Story et al. 2010). Recently, this antioxidant mechanism has been called into question given the low concentration of lycopene in the body relative to other antioxidant molecules, such as vitamin E (Erdman et al. 2009). This has led to speculation that observed health benefits may be due to the effect of lycopene or oxidative metabolites on gene expression (Erdman et al. 2009).

### 10.2.1 Lycopene

Lycopene is one pigment in a large family of plant pigments known as carotenoids. Carotenoids produce colours ranging from the yellow colour of squash, to the orange colour of pumpkins, to the red colour of tomatoes. Carotenoids also contribute to some plant food aromas (Rodriguez-Bustamante and Sanchezi 2007). Some carotenoids also possess provitamin A activity and have shown potent antioxidant activity. To date, more than 700 carotenoids have been identified (Britton et al. 2004). Lycopene is a carotenoid that is responsible for the red to pink colours of tomatoes and other foods. It is also known as non-provitamin A. Many other natural compounds like lycopene are generally stable to processing when present in the plant tissue matrix. Recently, lycopene has also been studied in relation to its potential health effects. Although promising data from epidemiological, as well as cell culture and animal, studies suggest that lycopene and the consumption of lycopene-containing foods may affect cancer or cardiovascular disease risk; more clinical trial data is needed to support this hypothesis. In addition, future studies are required to understand the mechanism(s) whereby lycopene or its metabolites are proven to possess biological activity in humans.

#### 10.2.1.1 Lycopene Chemistry

There are two primary types of carotenoids: hydrocarbon carotenoids and xanthophylls. Hydrocarbon carotenoids, such as lycopene, are composed entirely of hydrogen and carbon. In contrast, xanthophylls, such as lutein, contain oxygen in addition to carbon and hydrogen (Furr and Clark 1997). Some hydrocarbon carotenoids, such as β-carotene and α-carotene, can be enzymatically cleaved to form vitamin A. Lycopene lacks provitamin A activity because of the absence of a terminal beta-ion one ring (Rao and Rao 2007). Carotenoids typically contain 40 carbon atoms. Apo-carotenoids contain less than 40 carbon atoms. The prefix Apo is used to identify carotenoids that have been shortened in length by one or more carbons (Britton et al. 2004). Irrespective of the number of carbons, all carotenoids have an isoprenoid backbone (Britton et al. 2004).

The chemical formula for lycopene is $C_{40}H_{56}$. It has 11 conjugated and 2 unconjugated double bonds that permit for widespread isomerization, resulting in 1056 theoretical cis-trans configurations (Zechmeister 1944). Only a few isomers are actually found in nature, though, with the all-trans configuration of lycopene being the most common isomer found in foods (Nguyen and Schwartz 2000). The thermodynamic stabilities of the common lycopene isomers have been determined relative to the all-trans isomer. The 5-cis isomer was found to be the most stable followed by all-trans, 9-cis, 13-cis, 15-cis, 7-cis and 11-cis (Chasse et al. 2001). The cis-isomers of lycopene compounds are found in human blood plasma, breast milk and human tissues (Allen et al. 2002; Ferruzzi et al. 2001; Boileau et al. 2002). The colour of lycopene depends on its isomeric form. The all-trans isomer and cis-isomers of lycopene are red, whereas tetra-cis-lycopene possesses an orange type (Hackett et al. 2004; Zechmeister 1944).

#### 10.2.1.2 Lycopene Bioavailability

Lycopene bioavailability can be affected by a number of factors, including food processing and dietary composition. Lycopene can occur in several forms in fresh plant foods, including carotenoid-protein complexes in chloroplasts or in crystalline form inside chromoplasts (Parada and Aguilera 2007). The effects of processing and storage on lycopene structure and stability are of interest for a number of reasons. Improper processing and storage (i.e., exposure to light and oxygen) may alter the ratio of lycopene isomers or degrade lycopene entirely, making these food products less desirable to the consumer (Xianquan et al. 2005). Traditional commercial processing methods do not have a significant effect on lycopene levels or on cis/trans isomerization (Nguyen and Schwartz 1998). In fact, thermal processing generally improves lycopene bioavailability by disrupting cellular membranes, which allows lycopene to be released from the tissue matrix (Hackett et al. 2004). Multiple studies have shown that lycopene from thermally processed tomato products is more bioavailable than lycopene from fresh tomatoes (Allen et al. 2002).

Lycopene bioavailability is greatly affected by dietary composition. Given that lycopene is a lipid-soluble compound, consuming it with fat increases its bioavailability. For example, consuming salads with full-fat dressing results in higher blood carotenoid levels than eating salads with reduced fat dressing. When salads were consumed without fat in the same study, no measurable lycopene uptake occurred (Brown et al. 2004). A study by Unlu et al. (2005) showed a similar result, whereby the consumption of tomato salsa with avocado (as lipid source) led to a 4.4-fold increase in lycopene absorption as compared with salsa without avocado. Lycopene must first be released from the food matrix once ingested, before it is incorporated into mixed micelles. Micelles contain salts, cholesterol, and fatty acids from the meal, and the amphiphilic nature of the micelle structure helps to keep the lipophilic nutrients soluble in the aqueous digest (During and Harrison 2004). The micelles approach the unstirred water layer of the apical side of the in test in al cells (enterocytes), and lycopene passively diffuses across the apical membrane (During and Harrison 2004). Historically, researchers believed that lycopene was absorbed by the same route as dietary lipids, i.e., passive diffusion (Furr and Clark 1997), and this is still believed to be at least partially true. However, in the past 5 years, investigators have discovered that lycopene absorption can be facilitated by a cholesterol membrane transporter known as scavenger receptor class B type I (SR-BI) (During et al. 2005; Moussa et al. 2008). Research has also suggested that lycopene absorption may be facilitated by other transporters, but this has not yet been confirmed (During et al. 2005; Moussa et al. 2008). Once inside the enterocyte, lycopene is packaged with other dietary lipids into chylomicrons (During and Harrison 2004). Chylomicrons are then transported across the basolateral membrane and make their way into the lymphatic system, which eventually releases chylomicrons into the blood.

#### 10.2.1.3 Health Benefits of Lycopene

A study on effect of lycopene with respect to wide range of disease like cancer and cardio-vascular disease last few decades (Dahan et al. 2008; Riccioni et al. 2008).

We review here some studies lycopene that examined for biological effects on these diseases.

#### 10.2.1.3.1 Cancer

Cancer is one of the leading causes of human death in the world (American Cancer Society 2008). The consumption of fresh tomatoes and tomato products like tomato ketchups, sups and chutney, etc. has been connected with a reduced incidence of a number of different types of cancers, most notably prostate, lung, and stomach (Giovannucci 1999).

The protective effect of lycopene studied in relations to disease, prostate cancer is one of the mostwell investigated. Apart from prostate cancer, the effect of lycopene was also studied for the control of benign prostatic hyperplasia (BPH), the age-related non-cancerous over-growth of the prostate gland, and also negatively affects human health. Some of the solidest epidemiological indication support the consumption of tomato reduced the incidence of prostate cancer. The recent observational study by Giovannucci et al. (2002) found that the intake of more than 2 servings of tomato sauce per week was associated with a reduced risk of prostate cancer relative to less than one serving of tomato sauce per month. Lycopene intake was also related to reduced risk of prostate cancer, but the association was weaker (Giovannucci et al. 2002). A study was done by Lu et al. (2001) to quantified lycopene in blood plasma of 65 prostate cancer patients and 132 cancer-free controls. A significant inverse connotation was found between prostate cancer and plasma lycopene concentration, and it was observed between the highest and lowest quantity of intake of lycopene (Lu et al. 2001). Over the course of the study, it was found that there was an 18% reduction in risk of BPH in men who consumed the highest amount of lycopene as a food or a supplement (Kristal et al. 2008). In divergence, other observational studies have found weak relation between prostate cancer, BPH and lycopene intake (Chang et al. 2005; Peters et al. 2007). Most of these studies measured prostate specific antigen (PSA). PSA levels are routinely measured to determine prostate cancer risk and to monitor prostate cancer treatment (Chen et al. 2001). In one study by Chen et al. (2001), 32 prostate cancer patients consumed tomato sauce daily for three weeks (30 mg lycopene/day) before a radical prostatectomy. Serum PSA levels decreased after the dietary intervention by 20%. In addition, analysis of the prostate tissue revealed a reduction in the ratio of 8-hydroxy-2-′-deoxyguanosine (8-OHdG), a DNA adduct indicative of oxidative stress and associated with cancer, to 2′-deoxyguanosine (a marker of oxidative DNA damage) in the treated patients as compared with random controls (Chen et al. 2001). A separate clinical study examined the effects of tomato and tomato product feeding to men ($n = 41$) with and without soy protein isolate, having asymptomatic prostate cancer (Grainger et al. 2008). Consumption of tomatoes and tomato products daily (target intake level 25 mg/day lycopene) for 8 weeks reduced serum PSA levels in 34% of the subjects (Grainger et al. 2008). In contrast to the clinical trials showing a reduction in PSA levels as a substitute marker for prostate cancer status, some studies detected a weak effect (Barber et al. 2006) or no effect (Bunker et al. 2007) of tomato consumption or lycopene supplementation on prostate cancer risk.

Epidemiological recommendation has suggested that consumption of lycopene-containing foods may reduce the risk for breast cancer. A probable cohort study by Cui et al. (2008) found that lycopene consumption, as assessed by an FFQ, was inversely related to oestrogen and progesterone receptor-positive breast cancer risk in postmenopausal women. Two case-control studies comparing the dietary habits of women with and without breast cancer also observed a significant reduction in the odds ratio of those who consumed the maximum amount versus the less amount of dietary lycopene (Levi et al. 2001).

Lung cancer is the leading cause of cancer for both men and women. Most lung cancers are related to smoking. Lung cancer is of specific interest with esteems to carotenoid research given the increased risk of lung cancer development observed in smokers who consuming a β-carotene supplement (Omenn et al. 1996). Most recently, the Vitamins and Lifestyle (VITAL) troop study observed how earlier β-carotene supplement usage was associated with incidence of lung cancer development. The study conveyed that β-carotene supplementation was allied with a three-fold increase in lung cancer incidence (Satia et al. 2009). Epidemiological studies advise that higher consumption of lycopene is linked with either a reduced risk of lung cancer (Ito et al. 2005b) or no change in lung cancer risk, as compared with lower consumption levels (Yuan et al. 2003; Satia et al. 2009). A recent study by Gallicchio et al. (2008) stated the relation between lycopene and lung cancer. There is similar study done to stabilize the relation between lycopene and other cancer like colorectal cancer, ovarian cancer and pancreatic cancer. The study showed that lycopene intake reduces the incidence of colorectal cancer, ovarian cancer and pancreatic cancer (Ito et al. 2005a; Jeong et al. (2009).

##### 10.2.1.3.2 Cardiovascular Disease

Cardiovascular disease (CVD) is one of the deadliest diseases in the world. Increased plasma lycopene levels have been associated with reductions in CVD risk and have also been reported to improve biomarkers associated with CVD. Sesso et al. (2003) stated that the women who consume higher levels of tomato-based product were associated with a reduced risk of cardiovascular disease and myocardial infarction. Some clinical trials have also supported a relationship between cardiovascular disease and lycopene consumption. Some studies have shown that lycopene may decrease cholesterol synthesis and increase low-density lipoprotein (LDL) degradation (Arab and Steck 2000).

#### 10.2.1.4 Other Health Benefits of Tomato Fruits

***Lowering the Cholesterol Level*** Tomato fruits are free from cholesterol and are a good source of cholesterol-free diet. 100 g of tomato provides 9% of dietary fibre that helps to lower the cholesterol levels. Tomato fruits contain vitamin $B_3$ (niacin), that has been used to lower cholesterol levels (Shidfar et al. 2011).

***Reduce Heart Disease*** Tomato fruits are good source of mineral like potassium that have potential to lower the high blood pressure and reduce risk of heart disease. Vitamin $B_6$ and folate are also present in tomatoes which needed to the body to change a dangerous chemical called homocysteine into other, benign molecules. High levels of homocysteine can directly damage blood vessel walls and are associated with an increased risk of heart attack and stroke (Shidfar et al. 2011).

***Lowering Blood Pressure Efficiently*** The tomato fruits deliver significant drop in blood pressure. Continuously 8 weeks consumption of fresh ripen tomato or tomato extract (containing lycopene complex) exhibited a drop in both the blood pressure systolic by 10 points and diastolic by 4 points (Silaste et al. 2007).

***Defence from Cell Damage*** Tomato fruits are exceptional source of antioxidant molecules lycopene. Antioxidant molecules are transported in the body and neutralize the dangerous free radicals that damage cells and cell membranes. Free radicals intensify the development or severity of atherosclerosis, diabetic complications, asthma and colon cancer. High consumptions of lycopene have help to reduce the risk or severity of all of these illnesses.

***Regulates Blood Sugar*** Fresh ripen tomato fruits are an excellent source of chromium that and vitamin C helps to control sugar levels of diabetic patients. Vitamin C is one of the main reason for diabetes. Vitamin C supplements are benefits and cure the diabetes because it helps to processing the insulin and glucose.

***Counteract Acidosis*** Acidosis is a metabolic disorder that leads the main cause of calcium loss, fatigue, headaches, sleeplessness, muscle aches, acne, eczema, arteriosclerosis, sexual dysfunction, hormone imbalance, depression and degenerative conditions. Our bodies are designed to maintain an alkaline balance with a pH of $7.4 \pm 0.1$. Consuming plenty of alkaline minerals in our diets like calcium, magnesium, potassium and sodium helps our body to maintain its alkaline balance naturally. Tomatoes are outstanding sources of calcium, magnesium and potassium that can control acidosis (Burton and Reimers 2011).

***Reduce Migraines*** Tomato fruits are a good source of riboflavin, that helps to reduce the migraine attacks.

***Boost Immunity*** Due to consumption of fresh tomato fruits, it helps to sidestep the flu and colds, particularly for males. These common illnesses are widely believed to be rooted in carotenoid deficiencies, including low amounts of lycopene and beta-carotene in our body. Consumption of tomato juices contribute to build defences against colds and flu.

***Natural Sunscreen*** It has been displayed that lycopene in tomato fruits act as a natural sunscreen and provide protection against UV rays.

***Strengthen Bones*** A serving of fresh tomato fruits delivers 18% of the daily required amount of vitamin K, which promotes bone health. Vitamin K activates osteocalcin, the major non-collagen protein in bone. Osteocalcin mineralizes calcium molecules inside of the bone (Blum et al. 2005).

***Treatment of Vasodilation*** Vitamin C has efficiently controlled the proper dilation of blood vessels in the cases of atherosclerosis, congestive heart failure, high cholesterol, angina pectoris and high blood pressure. It has been found that supplements of vitamin C improve blood vessel dilation.

***Lead Toxicity*** Lead toxicity is an unadorned health problem found in children, particularly in the urban areas. Abnormal development and growth have been found in children who are exposed to lead. They develop behavioural problems, learning disabilities and have low IQ. It may damage the kidney and increase blood pressure in adults. Vitamin C supplements decrease the blood lead level. Therefore, by consumption of tomato lead toxicity can be reduced among the children. Because tomato is a rich source of vitamin C due to this, it can able to lower this risk factor (Barceloux 2009).

***Eye Disorder*** Cataracts are the most common reasons of visual problems. Decrease in the level of vitamin C in the lens of the human eye leads to increased number of cataracts. Increase of vitamin C in tomato consumption increases the blood supply to the visual zones of the body and helps to cure this eye disorder (Mayne 1996).

***Mood*** Vitamin C present in the tomato fruits plays a main role in the production of neurotransmitters, norepinephrine. Less amount of vitamin C can affect the mood of a person and are dangerous to the proper functioning of the brain (Foy et al. 1999).

***Wound Repair*** Due to consumption, accurate amount of fresh ripen tomato daily helps to provide the proper amount of Vitamin C that helps to repair wounds in the body. It enables the growth of the connective tissues that helps in the development of healing of wounds from our body (Shidfar et al. 2011).

## 10.3 Conclusion

Tomato belongs to the family Solanaceae, its botanical name is *Lycopersicon esculentum.* Tomato is termed as the most popular horticulture crops that is used to consume raw, cooked and processed form. It is a fruit of respectable nutritive value as it is fairly rich in vitamins (vitamin C), and other minerals like calcium, phosphorus and iron. Considering its low cost, it meets the requirements for presence in the daily diet of young and growing children. Tomato shows good antioxidant property due to the presence of lycopene. Lycopene is a non-provitamin A carotenoid that is responsible for the red to pink colours seen in tomatoes, pink grape fruit and other foods; lycopene is generally stable to processing when present in the plant tissue matrix. Recently, lycopene has also been studied in relation to its potential health effects. Dietary intake of tomatoes and tomato products containing lycopene has been shown to be associated with a decreased risk of chronic diseases, such as cancer and cardiovascular disease.

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# Radish

# 11

Arashdeep Singh, Savita Sharma, and Dolly

**Abstract**

Radish (*Raphanus raphanistrum*) is an annual and a biennial cool-season crop of ancient origin believed to be originated from Mediterranean South Asian region and grown in Southeast Asian countries. Radish is a root crop particularly grown for its taproot that varies in colour from white, pink, red, purple, and black and has appetizing flavour. The taproot edible as raw as it is palatable, juicy and crunchy with a pungent peppery pleasing taste. All botanical parts of radish such as leaves, stem, seeds, and pods are utilized in food in one or another way. Besides its consumption as fresh juice and in salad form, it is processed to traditional pickles, and its leaves and pods are used in traditional foods. It is also well known to cure various ailments and used from centuries in Southeast Asian countries as traditional medicine. With increasing interest of researchers in this root over last few decades to confirm its health claims, the natural molecules such as glucosinolates, isothiocyanates, phenols, flavonoids, anthocyanins and other bioactive substances are believed to be responsible for its medicinal activities. Leaves, seeds, peel and sprouts of radish are rich sources of many functional molecules that may have possible medicinal values. This chapter aims to summarize the history, production, botanical classification, chemical components and health beneficial properties of radish.

**Keywords**

Radish · Bioactive components · Antioxidant properties · Health benefits

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## 11.1 Introduction

### 11.1.1 Botanical Name, Common Name

Radish (*Raphanus raphanistrum* subsp. sativus (L.)) is a member of family Brassicaceae/Crucifarea, which belongs to genus *Raphanus* and species *R. Sativus*.

Radish is also known as Hung Loh Paak Tsai (China), Mooli (India), Daikon (Japan) Radisa (Sweden), Turp (Turkey), Labok (Malaysia), Mu (Korea), Rafano (Spain), Radis (France), and Radi (German) in various parts of the world.

### 11.1.2 History

Since radish has been cultivated for the past thousand years, its exact origin is unknown. From various studies, it was confined that radish is an ancient crop and has been originated in the eastern Mediterranean region of Asia and Europe from where it has been domesticated to the rest of the world. Radish cultivation is as old as 2000 BC. Data from domestication showed that, it is observed that its cultivation in China existed in 500 BC and in Korea in 100 BC (Kaneko and Matsuzawa 1993; Kalia 2005). From China, radish is introduced in Japan at around 700 AD. It was also used as food in ancient Egyptian around 2700–2200 BC before pyramids and was cultivated since thirteenth century BC, from where it was cultivated in Europe at around fifteenth to sixteenth century BC, and at this time around, it was introduced in America (Piluek and Beltran 1993). Greeks are first and foremost allied with the primary cultivation of radish. In the beginning of Christian period, it was also described in various roman writings and is introduced to the present world by Columbus (Peirce 1987). From the DNA studies, it was found that radish is an amalgam involving *B. raphanistrum*/*B. oleracea* and *B. nigra* lineages (Yang et al. 2000; Lim 2015). *Raphanus raphanistrum*, a weed widely distributed in Europe, is related to radish cultivation with different evidences existing from the ecological and morphological regions of the world. *R. raphanistrum* Linn., *R. maritimus* Smith, *R. landra* Morett. and *R. rostratus* DC are the five most important wild spices of radish found in Mediterranean region that contributes to the present day cultivation of radish around the world.

### 11.1.3 Production

Radish accounts for around 2% of total world production of vegetables with estimated production of seven million tons per year. China, Japan and Korea are the main South Asian countries, where radish is of high importance and cultivated over wide area (Schippers 2004). In India, radish is mainly cultivated in West Bengal, Punjab and Haryana. West Bengal leads in the production of radish with 539.00 thousand tons, followed by Haryana with production of 531.51 thousand tons and Punjab with production of 337.93 thousand tons, accounting for the total share of 17.86, 17.61 and 11.20% of the total radish production in India (APEDA 2018). Normally, radish yields 10–15,000 kg/hectare, with Chinese radish yield varying from 30 to 44,000 kg/hectare. Radish covers around 1.2 million hectare area with production of 44.6 million tons in China, which accounts for 40% of the total world area under radish production and 47% of the total radish produced in the world (Zhang et al. 2019). India follows China with the production of radish, which accounts for 8.07 million ton followed by Russia, Korea and Ukraine with production share of 12.33, 4.94, 3.35 and 2.34%, respectively (APEDA 2018). The main varieties of radish available in the world market are Cavelier, Cherry belle, Mirabeau, Comet, Sparkler, Scarlet Globe, French breakfast, Cincinnati Market, Ilka, White Iscle, Long Scarlet, Plum purple, Daikon long, Strasburg, Stuttgart, White Chinese and Vienna, Rougette, Golden Globe, Stela, China Rose, Long and Round Black Spanish, Sakurjima and Tarzan, depending upon the size, shape and season of the root. Jaunpuri, Bombay Long White, Long Red, Japanese white, Punjab Safed, Kalyani white, Chinese pink, white Icicle, Pusa desi, Pusa Himani, Pusa Chetki, Pusa Reshmi, Japanese white and Ganesh Synthetic are the major varieties of radish cultivated in different parts of India.

### 11.1.4 Botanical Description

Radish is both an annual and a biennial cool-season crop that belongs to Brassicaceae family. Radish is primarily grown for their tap root (edible portion of radish), develops from both the primary root and the hypocotyl. Roots vary greatly in size, shape and other external characteristics, as well as in the length of time they remain edible. The shape varies from globular to long tapering and cylindrical. The colour of the skin vary from whitish to pinkish, to reddish, to purplish, to greenish and to blackish; however, the fleshy tissue remains white or exhibits various shades of scarlet. Colour of the roots was principally controlled by anthocyanin pigments while they obtain red pigment from anthocyanin pelargonidin and purple pigment from cyanidin. Radish roots are long to slender in diameter with root length varying from 2.5 to 90 cm. Depending upon the cultivar, the height of total plant varies from 30 to 120 cm, having 0.2–0.6 m tall and erect branched stem. Leaves of the mature radish were organized in a rosette pattern, which are alienated pinnately with an overstated terminal lobe and minor lateral lobes. The leaves of the radish are basically alternate, glabrous to sparingly hispid and categorized into lower or higher leaves. Lower leaves are 5–30 cm long, having 3–5.5 mm long petiole, oblong baldes and dented lobes, while higher leaves are relatively small with shorter petiole, undivided, subdentate and subsessile. The inflorescence of radish is a typical elongated, erected, oblong raceme of Cruciferae. Flowers are 1.5–2 cm in width, white to pink and purple colour with purple veins, having four erected sepals and clawed petals, six stamens and 3–4 cm long style. The seed capsule, Siliqua or seedpod is 1.5 cm wide with length ranging from 3 to 7 cm, having 6–12 seeds/pod with long conical seedless beak. The seeds of radish are globose to ovoid in shape, 2.5–4 mm in diameter. At fruit maturing, the colour of seeds are somewhat yellow, which turns reddish-brown with age (Kalia 2005; Lim 2015).

Radish is a fast-growing, cool-season crop, and for best quality crop, it grows well on deep, friable, well trickled, and sandy or clay loam or alluvial soil. The soil having good amount of humus and better moisture retention capacity is most sought after for high-quality produce. Heavy soil results in small or misshapen roots, while sandy soil lacks humus and does not retain moisture well, hence not preferred for radish cultivation. Radish grows very well over a relatively wide pH range but grows well in soils having slightly acidic or near neutral pH, which ranges from 6.5 to 7.0 (Lim 2015). For the growth and germination of seeds, moist condition with temperature of 20–28 °C is required, and for the best quality root growth and development, temperature between 10 °C and 18 °C is essential under moderate day length. Crop matures in 3–4 weeks under normal weather conditions and in 6–7 weeks during cold weather. Still being a cool-season crop, it can tolerate slight warm temperature; however, increase in temperature increases the pungent flavour in root, and at higher temperature, the roots become fibrous with repulsive flavours.

## 11.2 Antioxidant properties

### 11.2.1 Root and Juices

The radish extracted with ethyl acetate exhibits highest antioxidant activity as the values for $IC_{50}$ vary from 1275.96 to 1948.70 mg/l after 8–24 h of extraction, while with ethanol and hexane higher values of $IC_{50}$ values show the poor antioxidant activity of the extracts (Pasau 2019). Maximum total phenolic content (TPC) (26.94–37.98 mg GAE/g) and total flavanoid (TF) (3.56–5.74 mg QE/g) of radish were observed when it was extracted with ethyl acetate for 8–24 h; however, when extraction medium were ethanol and hexane, the values for TPC and TF were significantly lower (Pasau 2019). The antioxidant activity, TPC and TC were reported radish was extracted with ethyl acetate at pH 4.5 at 25 °C, while the values for antioxidant activity, TPC and TF decreased as the pH increased from 4 to 7 and temperature of extraction increased from 70 °C to 90 °C. Bors et al. (2015) in their research stated that antioxidant properties in radish roots vary from 12.23% to 27.12% RSA of DPPH, in three different coloured radish varieties. The red colour radish exhibits highest DPPH radical scavenging activity of 27.12%, followed by white radish 22.33% and lowest was reported in black radish variety with antioxidant activity of 12.23%. Similarly, red radish exhibits highest TPC of 5.48 mg GAE/g, while for white and black radish TPC is around 4.42–4.75 mg GAE/g, respectively (Bors et al. 2015). Hanlon and Barnes (2011) in their study reported that total TPC in radish roots varies between 2 and 4 μg GAE/g.

The sulphoraphene content in the radish differs significantly owing to the variety and skin colour difference, and it varies between 193.28 and 2128 μg/g among 12 different radish varieties of different origins (Beibei et al. 2015). Goyeneche et al. (2015) in their study testified that roots of radish have lower antioxidant properties in comparison to the radish leaves; they reported that the roots of radish exhibit antioxidant activity of 1.36, 1.96 and 11.09 mmol TE/100 g in terms of DPPH, FRAP and ORAC assays, respectively. Radish roots contain total phenolic content of 341.45 mg GAG/100 g and flavanoid content of 267.47 mg quercetin/100 g, which were significantly lower in comparison to the TPC and TF present in the leaves (Goyeneche et al. 2015). The most abundant free phenolic acid reported in the radish roots is pyrogallol acid (81.43 mg/100 g), while vanillic acid (158.63 mg/100 g) is the most abundant bound form. Other phenolic acids present in free form in radish roots are Rutin hydrate (9.15 mg/100 g), vanillic acid (23.12 mg/100 g) and gallic acid (5.43 mg/100 g), while p-coumaric acid (52.32 mg/100 g), caffeic acid (7.11 mg/100 g) and trans-ferulic acid (34.40 mg/100 g) are present in bound form (Goyeneche et al. 2015).

Park et al. (2016) reported that TPC and TFC in three red radish cultivars varies between 0.0088 and 0.0664 mg/g, and 0.0060 and 0.0096 mg/g, respectively, while Hong Feng No. 1 red radish does not exhibit any flavanoid content. They also observed that amongst three radish varieties, Man Tang Hong exhibits highest anthocyanin content (1.89 mg/g) followed by Hong Feng No. 1 (0.23 mg/g), while in contrast, Seo Ho radish does not have any detected anthocyanin. Among the anthocyanin detected, pelargonidin 3-(p-coumaroyl) diglucoside-5-(malonyl) glucoside (0.45 mg/g) and elargonidin 3-(feruloyl) diglucoside-5-(malonyl) glucoside (0.47 mg/g) are the most predominant radish cultivars studied. Cyanidin 3-(glucosyl) rhamnoside, pelargonidin 3-(caffeoyl) diglucoside-5-(malonyl) glucoside, pelargonidin 3-(feruloyl) diglucoside-5-(malonyl) glucoside, pelargonidin 3-(feruloyl) (caffecoyl) diglucoside-5-(malonyl) glucoside and pelargonidin 3-(p-coumaroyl) (feruloy) diglucoside-5-(malonyl) glucoside were not reported in Hong Feng No. 1; however, they are present in Man Tang Hong radish. The antioxidant activity reported as superoxide radical scavenging activity varies between 57.69 and 68.87% in 1000 μg/ml, and in terms of DPPH, it varies between 5.84 and 20.78% in 1000 μg/ml in all the three red radish cultivars, with highest being observed in Man Tang Hong cultivars.

Karadeniz et al. (2005), while studying the bioactive components in different vegetables grown in turkey, observed that red radish antioxidant activity of 29.4% and total phenolic content of 1056 mg GAE/kg, which was significantly higher in comparison to potato, onion and spring onion while it follows red cabbage. The red radish had total flavanoid content of 179 mg/kg, while the total flavanoid content as much higher in spring onion and red cabbage (Karadeniz et al. 2005).

White radish exhibits DPPH and ABTS radical scavenging activity of 25.72% and 42.20%, respectively, which was lower than antioxidant activity of ginger and garlic (Somman and Siwarungson 2015). TPC and TFC in white radish were found to be 0.53 mg GAE/g and 1.84 mg RE/g, respectively. Sreeramulu and Raghunath (2010) in their study reported that among the root and tubers commonly consumed in India, white radish exhibits antioxidant activity of 29.02 mg TE/100 for DPPH assay and 1294.36 mg FeSo4 equiv./100 g. The TPC of the white radish was 66.73 mg GAE/100 g.

Beevi et al. (2012) in their study reported that total phenolic content of the radish varies from 16.80 to 180.50 mg GAE/g when extracted with water and hexane and water. Among the different extract solvent, catechin (10.54 mg/g) and sinapic acid (4.83 mg/g) were predominant in water extract, while sinapic acid (5.29 mg/g) and ferulic acid (2.65 mg/g) were predominant in methanol extract. In the ethyl acetate extract, sinapic acid predominates the phenolic acids. Antioxidant activity as ferric-reducing power (FRP) varies between 1.34 and 2.68 mmol/g for methanol, hexane and water extract, while extracts of ethyl acetate and chloroform show FRP of 0.23–0.82 mmol/g. Metal chelating activity (MCA) for extracts of ethyl acetate, methanol, water and hexane ranges between 20.86 and 32.15%. Methanol extract from radish showed DPPH scavenging activity as $IC_{50}$ value of 64 μg/ml, while $IC_{50}$ values for superoxide ($O^{-}{}_{2}$), hydrogen peroxide ($H_2O_2$) and nitric oxide (NO) radicals were 60 μg/ml, 259 μg/ml and 137 μg/ml. Lower $IC_{50}$ values mean strong antioxidant properties.

Sangthong et al. (2017) in their study reported that radish cultivars caudatus Alef had 6 different glucosinolates, 13 different isothiocyanates, 5 types of indoles, 4 different flavanoids, 2 kinds of alkaloids and thiocyanates, 1 oxazolidine and dialkyl disulphide compounds. Isoalliin and butyl 1- (methylthio) propyl disulphide are two compounds that were first identified in radish. Salah-Abbès et al. (2009c) in their study reported that isothiocyanate content in Tunisian radish is 38.98 μmol/100 mg. Koley et al. (2020) in their study reported that root periderm exhibits strong antioxidant potential in comparison to root xylem (Koley et al. 2020). They found that FRAP-, CUPRAC-, DPPH- and TEAC-based antioxidant activities were 20.4, 28.1, 13.04 and 17.8 μmol TE/g for the root periderm, while they are 3.5, 7.8, 2.24 and 2.3 μmol TE/g for root xylem, respectively. They also reported that root periderm is composed of 78% of total acylates anthocyanins, 2% of total non-acylates anthocyanins, 1% of total phenolic acids, 16% of total acylated flavonols, 2% of total non-acylated flavonols and 1% of total flavonones. While root xylem is primarily composed of 90% of total acylated anthocyanins, 2% of total phenolic acids and 8% of total acylated flavonols.

Red radish is a good source of anthocyanins and contain 12 different types of acylated anthocyanins (Otsuki et al. 2002), among these six new compounds were isolated and quantified, which belongs to pelargonidin anthocyanin class. Study of Wang et al. (2010) informs that pelargonidin, derivatives of acylated anthocyanins present in red radish, exhibits significant antioxidant activities in terms of FRP and ABTS radical scavenging activity in dose-dependent mode. Total anthocyanin content in Chinese red radish cultivars varies between 63.77 and 160.74 mg/100 g, and these can be served as potential abundant source of natural anthocyanins (Jing et al. 2012). They also reported that the glucosinolates content varies between 59.69 and 163.91 mg/100 g in Chinese red radish cultivars.

Hanlon and Barnes (2011) in their study reported that mature taproot of eight different radish varieties have 17.1–100.0 μmol/g of glucosinolate and 3.9–7.6 μmol/g of isothiocyanate. Glucoiberin, glucoerucin, progoitrin, glucobrassicin, 4-hydroxyglucobrassicin, and 4-mithoxyglucobrassicin are the main glucosinolates present in the mature taproots. The antioxidant activities as FRAP and ORAC activities for the radish cultivars vary between 18.5 and 53.9 µmol AAE/g and 200 and 345 µmol TE/g, respectively. TPC varies between 2.0 and 4.2 µg GAE/g and total anthocyanin content varies from 1.56 to 6.81 mg Cy3-GlE/g among different radish cultivars, with exception for Nero Tondo, Miyashige and Ping Pong, which does not exhibit any anthocyanin content (Hanlon and Barnes 2011).

Beevi et al. (2009) reported that isothiocyanate content of root of radish varies from 0.42 to 1.18 mg/g, when extracted with different solvents such as water, methanol, ethyl acetate and chloroform, with highest being reported for chloroform and lowest for water extract. In further studies, Beevi et al. (2010a) reported that hexane fraction of the roots exhibits higher total isothiocyanate content (3.81 mg/g) in comparison to acetone fraction (1.82 mg/g), and these levels are significantly higher in comparison to those present in leaves and stem of radish. Among the individual isothiocyanates, 4-(methylthio)-3-butenyl isothiocyanate (2.91 mg/g) is predominant in hexane fraction, followed by allyl isothiocyanates, while in the acetone fraction, lead was taken by phenyl isothiocyanate (0.39 mg/g), followed by allyl isothiocyanates (0.18 mg/g) and 4-(methylthio)-3-butenyl isothiocyanate (0.12 mg/g).

### 11.2.2 Leaves

Leaves of radish also exhibit strong antioxidant properties owing to the presence of various bioactive compounds present in them. Red radish leaves exhibit antioxidant activities of 1.76, 3.39 and 39.48 mmol TE/100 g d.m as quantified by DPPH, FRAP and ORAC assays, respectively (Goyeneche et al. 2015). Leaves exhibit 3.6 fold higher antioxidant potential in comparison to roots when determined by ORAC method. They also reported that TPC in the leaves of red radish was 695.07 mg GAE/100 g, which are two times higher than roots. The leaves also exert four times higher TFC in comparison to roots and TFC in the leaves of red radish was 1042.73 mg QE/100 g (Goyeneche et al. 2015). Effective antioxidant potential of radish leaves extracts was due to the presence of phenolics and flavanoids, which exerts better radical scavenging properties (Beevi et al. 2012). Goyeneche et al. (2015) reported that in the free form of phenolics acid, coumaric acid, caffeic acid, trans-ferulic acid, epicatechin, tyrosol and trans-sinapic acids are mainly present, while vanillic, coumaric and trans-ferulic acids are the main phenolic compounds present in the bound form in radish leaves, with epicatechin acid and coumaric acid being most profuse in free and bound forms, respectively. They also reported that out of the total phenolic compounds, 55% were accounted by free phenolics and rest accounted for bound phenolics.

Beevi et al. (2010c) in their study reported that leaves of the radish are potentially good source of phenolic acids such as catechin, vanillic acid, syringic acid, ferulic acid, sinapic acid, p-coumaric acid, myricetin and quercetin. The acetone and methanol extracts of the leaves were reported to have 78.77–86.16 mg CE/g of total phenolics, which were comparable to green and black tea. The water and ethyl acetate extracts of radish, however, exhibit comparatively lower total phenolic in the leaves, which ranges between 34 and 37 mg CE/g. Their study also reported that the polarity of solvents had significant influence on the rendering of phenolic compounds from the samples. Catechin was the primary phenolics in water extracts, while in methanolic extracts vanillic acid is abundant followed by ferulic, sinapic, and p-coumaric acid. Myricetin is the prime flavonoid reported in radish leaves when extracted using ethyl acetate as solvent. FRAP antioxidant power of the leaves extracted with water, acetone and methanol varied between 1.17 and 2.83 mM FeSO4/g, which has higher value reported for the methanol extracts. While for ethyl acetate and chloroform extracts, the antioxidant activities varied between 0.57 and 0.89 mM FeSO4/g, which were significantly lower in comparison to other extracts in the same study. Percent inhibition of linoleic acid peroxidation values of radish leaves extracts ranges between 54 and 82%, with significantly higher values for methanol extracts followed by water extract, acetone extract and ethyl acetate extract. Beevi et al. (2010c) also reported that reducing power and metal chelating activity of the methanol extract of the radish leaves were 0.698 and 30.83%, respectively, which were significantly higher than leaves extracted with water and acetone as solvent. Scavenging ability of different leaves extracts as $IC_{50}$ values for DPPH radicals were very strong for the methanol extracts as DPPH exhibits 0.031 mg/ml $IC_{50}$ value, while for other extracts the values varied between 0.215 and 1.86 mg/ml, exhibiting very poor scavenging activities. Similarly, the strongest $IC_{50}$ values for $O^{-}_{2,}$ $H_2O_2$ and NO radicals were also exhibited by methanol leaves extract in comparison to other solvent extracts. The $IC_{50}$ values for superoxide radical, nitric oxide and hydrogen peroxide radicals were 0.023 mg/ml, 0.056 mg/ml and 0.067 mg/ml, respectively. Isothiocyanate (ITC) content in the radish leaves ranges from 0.12 to 0.21 mg/g among various solvent extracts (Beevi et al. 2009). They also reported that ITC content from chloroform and ethyl acetate extract were higher, while water and methanol contains somewhat similar and lower levels of ITC. Isothiocyanates are primarily responsible for the antibacterial activity of radish plant. They also reported that root contain higher levels of ITC in comparison to leaves and stem. Total isothiocyanate content in the acetone and hexane extract of the leaves was 0.87 and 0.24 mg/g, respectively (Beevi et al. 2009). Their study also reported that acetone extract has allyl, benzyl, phenethyl, phenyl, and 4-(methylthio)-3-butenyl isothiocyanate, while hexane extract only has allyl, 4-(methylthio)-3-butenyl and phenyl isothiocyanate. Radish leaves had much higher ITC content in comparison to the stem part, while its values were much lower in comparison to root of the radish (Beevi et al. 2009).

The radish leaves exhibit strong antioxidant potential owing to higher levels of phenol compounds, flavanols, tocopherols and carotenoids (Goyeneche et al. 2015). Chlorophyll and carotenoids in plant are indicators of good photosynthesis activity. Ashraf et al. (2016) in their studies reported that radish leaves contain 0.53 mg/100 g, 0.18 mg/100 g, 0.46 mg/100 g of cholorophyll a, b and B carotene, respectively. They also reported that foliar application of plant extracts at 3% level significantly enhanced the content of total carotenoid and total chlorophyll. However, increase in the concentration foliar application of plant extracts decreased their contents in radish leaves.

4-methylthio-3-butenyl is the principal glucosinolate present in radish leaves and content of glucosinolate is around 0.8–1.1 μmol/g, which was much lower in comparison to that present in the radish root (Levine et al. 2008). They also reported that lower atmospheric pressure during the growth and development of the radish decreased the glucosinolate content. Antioxidant activity measured as ORAC assay and reported as Trolox equivalents was 120 μmol/g, which was lower in comparison to the antioxidant activity of the radish root (Levine et al. 2008).

Eugenio et al. (2017) in their study reported gallic, caffeic, chlorogenic acid, vanillin, p-coumaric acid, ferulic acid, rosmarinic acid, quercetin and trans-cinnamic acid are the primary phenolic acids present in the radish leaves. Among these phenolic acids, rosmarinic acid and chlorogenic acid are the predominant with values of 21.20 and 8.84 mg/ml, respectively. TPC in the radish leaves were 91.8 mg GAE/g as reported by Eugenio et al. (2017), and the contents were higher in comparison to the TPC content present in leaves of other tuber roots. Eugenio et al. (2017) also reported that radish leaves exhibit higher antioxidant activities in comparison to leaves of yam, beetroot, sweet potato and carrot. They found that antioxidant activity as $IC_{50}$ was 422.7 μg/g for radish leaves, while for other leaves it ranges between 1068.3 and 1577.7 μg/g. Similarly, highest antioxidant activity as FRAP was also reported in radish leaves (6.658.5 μM $FeSO_4$/g), while for yam, beetroot, sweet potato and carrot leaves antioxidant capacity as FRP ranges between 690.3 and 1679.95 μM $FeSO_4$/g. The antioxidant activity as determined by β-carotene in radish leaves was 290.7 $IC_{50}$, which for other leaves varies between 280.2 and 2495.0 mg/L. Eugenio et al. (2017) reported β-carotene derived from radish leaves had greater protective effect against the linoleic acid oxidation followed by yam, sweet potato and carrot leaves.

Leaves of red radish had significant anthocyanins, which are basically due to presence of pelargonidin 3-O- [2-O-(b-D-glucopyranosyl)-6-O-(trans-caffeoyl)-b-D-glucopyranoside]-5-O-(6-O-malonyl-b-D-glucopyranoside) pelargonidin 3-sophoroside-5-glucoside, pelargonidin 3-[2-(glucosyl)-6-(trans-p-coumaroyl)-glucoside]-5-glucoside, pelargonidin 3-[2-(glucosyl)-6-(trans-feruloyl)-glucoside]-5-glucoside, pelargonidin 3-O-[2-O-(b-D-glucopyranosyl)-6-O-(cis-p- coumaroyl)-b-D-glucopyranoside]-5-O-(6-O-malonyl-b-D-glucopyranoside) pelargonidin 3-[2-(glucosyl)-6-(trans-p-coumaroyl)-glucoside]-5-(6-malonylglucoside) and pelargonidin 3-[2- (glucosyl)-6-(trans-feruloyl)-glucoside]-5-(6-malonylglucoside) compounds in the leaves as (Tatsuzawa et al. 2008).

Goyeneche et al. (2018) found that bioactive components can be extracted of from radish leaves employing supercritical fluid extraction technology using $CO_2$ at 400 bar pressure at 35 and 40 °C. They reported that radish leaves exhibit antioxidant activity of 359 mg TE/100 g when extraction was done at 35 °C with 400 bar pressure and 403 mg TE/100 g when extraction temperature was increased to 40 °C, keeping the pressure constant. They also revealed that the total phenolic content of the leaves of radish at foresaid conditions is 1375 mg GAE/100 g and 1455 mg GAE/100 g, respectively. Highest total flavanoid content of 14.6 mg QE/g was observed when extraction was done at 35C/300 bar pressure and 21.8 mg QE/g when extraction was done at 40 C/400 bar pressure. Goyeneche et al. (2018) concluded that supercritical extraction using $CO_2$ can be used as technique to get extracts rich in phenol components and higher antioxidant potential in comparison to extracts obtained using traditional methods.

Leaves of wild radish showed total phenolic acids of 0.74 mg p-CAE/100 g, total phenolic compounds of 33.59 mg FAE/100 and total flavanoids of 33.26 mg QE/100 g and tocopherol content of 99 mg/100 g (Iyda et al. 2019). The leaves of wild radish are power house to 14 phenolic acids and 12 flavanols. The most predominant phenolic acid present in leaves of wild radish are ferulic and *p*-coumaric acid, while quercetin and kaempferol glycoside are the most prominent flavanols present. Antioxidant activity in terms of $EC_{50}$ values are 4.0 mg/ml for DPPH assay, 3.23 mg/ml for ferricyanide blue assay, 0.56 mg/ml for β-carotene/linoleate assay and 0.16 mg/ml for TBARS assay. Leaf lamina of purple radish contains 6% total flavanones, 2% total isoflavanones, 22% total flavanones, 8% total acylated anthocyanins, 3% total non-acylated anthocyanins, 3% total phenolic acids, 12% total acylated flavonols and 44% of total non-acylated flavonols (Koley et al. 2020). While leaf petiole contains 9% total phenolic acids, 6% total non-acylated anthocyanins, 53% total acylated anthocyanins, 4% total flavonones, 15% total non-acylated flavonols and 10% of total acylated flavonols. DPPH scavenging activity of leaf lamina (20.86 μmol TE/g) was significantly higher than leaf petiole (3.50 μmol TE/g). Similarly, antioxidant activity in terms of FRAP, CUPRAC and TEAC was also higher for leaf lamina with values of 29.7, 45.2 and 25.7 μmol TE/g, respectively, while the values for leaf petiole are 5.2, 8.1 and 4.8 μmol TE/g, respectively.

### 11.2.3 Stem

Stem of radish is generally discarded as waste, while it is a good source of antioxidants. Beevi et al. (2010b, c), in their study reported that ITC content in the stem of radish ranges between 0.12 and 0.16 mg/g from chloroform, acetone, hexane and ethyl acetate extracts. Isothiocyanates (ITC) are primarily responsible for the antibacterial activity of radish plant. Root contains higher levels of ITC in comparison to leaves and stem. The TPC in the stem of radish extracted with acetone and methanol was found to be around 56.75 mg/g, while in water and ethyl acetate extracts the value of TPC ranges between 23 and 36 mg/g (Beevi et al. 2010b). They also reported that TPC level in the stem was significantly lower than the level in leaves. Study of Beevi et al. (2010b, c) found that catechin, vanillic acid, ferulic acid, sinapic acid, o-coumaric acid and myricetin are most abundant phenolic compounds present in the stem of radish. While catechin was higher in water extract, vanillic, ferulic, sinapic and o-coumaric acids were higher in methanol extract. Various studies have earlier reported that the level of phenolic varies among different solvents due to their different polarities (Beevi et al. 2010a, b, c). Beevi et al. (2009) in their study reported that total isothiocyanate content in the acetone extract of the stem is 0.16 mg/g, while in the hexane extract it was 0.12 mg/g. They also reported that of the different individual isothiocyanate content, acetone extract has allyl, benzyl, phenethyl, and 4-(methylthio)-3-butenyl isothiocyanate, while hexane extract has allyl, 4-(methylthio)-3-butenyl and phenyl isothiocyanate.

Antioxidant activity in terms of FRAP was in the range 1.68–2.83 mM/g when extracted with water, methanol and acetone solvents (Beevi et al. 2010b). They also reported that FRP of stem extracts was significantly lower than the leaves extracts. Methanol extract exhibited FRP of 0.497 OD and metal chelating activity of 30.83%, which was significantly higher comparison to reducing power and metal chelating activity of other solvents. The scavenging ability of different methanol and acetone extract from stem showed $IC_{50}$ values (half maximal inhibitory concentration) in the ranges between 0.042 and 0.225 for DPPH radical, 0.052 and 0.189 for superoxide radical, 0.197 and 0.680 for hydrogen peroxide and 0.062 and 0.198 for nitric oxide radicals. Stem exhibited most strong scavenging activity with $IC_{50}$ value of 60–197 μg/ml in methanolic extract. They also reported that leaves exhibit higher antioxidant potential and radical scavenging activities in comparison to stem due to high phenolic content in the later. Stem of radish is a good source of isothiocyanates; however, it only contains 1105.14 μg/g of sulphoraphene, while sulphoraphane was not detected because it was lower than the detection limit (Sangthong and Weerapreeyakul 2016).

### 11.2.4 Seed

Mature seeds of the radish are good source of bioactive components such as alkaloids, alkaloids, glucosinolates, brassinosteroids and flavonoids (Sham et al. 2013). Li and Jing (2010) in their study reported that seeds of radish contained alkaloids of 1.056–2.62%, which exhibits antioxidant activity. Sinapine present as sinapine thiocyanate is the prime bioactive alkaloid present in the seeds of radish (Xing et al. 2012). Mature seeds of radish are also good source of glucosinolates and isothiocyanate. Hu et al. (2010) in their study reported that radish seed had glucosinolate content of 73.5 $\mu$mol/g, which comprises of 40.345 $\mu$mol/g of glucoraphenin and 0.762 $\mu$mol/g of glucoraphanin. Radish seeds also contain good amount of isothiocyanate that comprises of 77.19–89.19 $\mu$g/g of sulphoraphane and 7 mg/g of sulphoraphene (Liang et al. 2004; Kuang et al. 2013). Studies of Schmidt et al. (1991) and Schmidt et al. (1993) reported that seeds of radish contain brassinosteroids such as teasterone, castasterone, 28-homoteasterone and brassinolide. Total flavanoid content of radish seeds is 0.60%, which also exerts antioxidant properties. Tocopherols, which also exert antioxidant properties, are also present as -tocopherol with values of 233$\mu$g/g in radish seed (Xue et al. 2005).

Kim et al. (2015) reported that seeds of radish contain different phenolic compounds and alkaloids, which includes methyl (3*R*)-hydroxyl-3-(4-hydroxyl-3, 5-dimethoxyphenyl) propanoate, sinapic acid, methyl ester, sinapic acid, dihydrosinapic alcohol, *E*-ferulic acid, *Z*-ferulic acid, *p*-anisic aldehyde, syringic aldehyde, methyl 7-hydroxyoxindole-3-acetate, 4-hydroxy-3- indolecarbaldehyde and methyl oxindole-3-acetate. The seeds of radish also contain four derivatives of megastigmane, which includes (−)-dihydrovomifoliol, (6*R*, 9*R*)-vomifoliol, (6*S*, 9*R*)-vomifoliol and (6*S*, 9*S*)-vomifoliol. Due to the presence of these compounds, seeds of radish exert various antioxidant and antiproliferative activities (Kim et al. 2015). Pocasap et al. (2017) in their study reported that seeds of radish contains 0.89 $\mu$g/mg of sulphoraphane and 9.26 $\mu$g/mg of sulphoraphene.

Seeds of red, white and black radish cultivar vary significantly in terms of their antioxidant potential and TPC (Bors et al. 2015). Seeds of red radish exhibits highest antioxidant activity (AOA) of 44.79% DPPH radical scavenging activity, followed by black and white radish seeds with AOA of 43.70% and 34.95%, respectively. They also found that the total phenolic content of red and black radish seeds is at par with average values of 10.71 mg GAE/g, while white seeds had TPC of 8.87 mg GAE/g. The seeds exhibit higher AOA and TPC in comparison to the mature roots (Bors et al. 2015).

Seeds of radish had 6 mgGAE/g of TPC and 17 mg QE/g of TF, which were significantly higher in comparison to broccoli seeds (Pajak et al. 2014). They also reported that radish seeds exhibit antioxidant activity of 10.52 mg Trolox/g for ABTS, 7.50 mmol $Fe^{2+}$/100 g for FRAP and had DPPH radical scavenging activity of 3.10 mg TE/g, which were significantly higher when compared with seeds of sunflower and broccoli. Pajak et al. (2014) also reported that radish seeds have free phenolic content of 10.46 mg/100 g and bound phenolic content of 1059 mg/100 g. Caffeic acid (3.74 mg/100) is predominant free phenolic acid present in the radish seeds, followed by ferulic acid (2.10 mg/100 g). In the bound phenolic fraction, sinapic acid (994 mg/100 g) is present in higher concentration followed by ferulic acid (35.64 mg/100 g), vanillic acid (11.7 mg/100 g), p-coumaric acid (6.09 mg/100 g), caffeic acid (4.50 mg/100 g), with gallic and protocatechuic acids. The total bound flavanoids content present in radish seeds is 5.40 mg/100 g, which is predominated by luteolin (3.54 mg/100 g) and quercetin (1.36 mg/100), with small amount of kaempferol (0.50 mg/100 g) (Pajak et al. 2014).

Radish seeds cv. Rebel contained 145 μmol/g of total glucosinolates while cv. Bolide has 70 μmol/g total glucosinolates with 96% of them belongs to aliphatic glucosinolates (Martinez-Villaluenga et al. 2010). Glucoraphenin is the most predominant aliphatic glucosinolates present in both the radish cultivars, that is 129 μmol/g in cv. Rebel and 64 μmol/g in cv. Bolide, while other glucosinolates present in the seeds of both the radish cultivars were glucoraphanin, napoleiferin and glucoraphasatin. Among indole glucosinolates, which are present in lower quantity, 4-hydroxyglucobrassicin was the predominant one followed by glucobrassicin, while 4-methoxyglucobrassicin and neoglucobrassicin were present in traces in Bolide radish cultivars (Martinez-Villaluenga et al. 2010). Germination of radish seeds brought a significant reduction in the glucosinolate content. The antioxidant capacity of radish cv. Rebel and Bolide was found to be 102.63 and 161.53 μmol Trolox/g, respectively, and it was significantly enhanced by germination of the seeds in both cultivars (Martinez-Villaluenga et al. 2010).

Aguilera et al. (2015) in their study observed that seeds of radish have 6.7 mg GAE/g of TPC, 0.1 mg CAE/g and 0.1 mg CyE/g each of total catechins and proanthocyanidins and 277.2 pg/g of melatonins. Their study also reported that red cabbage and broccoli exhibit higher total phenolic content and melatonin content than radish, while the levels of TPC and melatonin were lower in onion, lentil, alfalfa and mungbean seeds. The antioxidant activity in terms of DPPH was lowest for radish seeds (1.4 μmol Trolox/g), while it ranged between 1.7 and 2.7 μmol Trolox/g for alfalfa, lentil, mungbean, broccoli and red cabbage. Antioxidant activity in terms of FRAP and ORAC assay for radish were 30.6 and 1.5 μmol Trolox/g, respectively, while FRAP and ORAC values for alfalfa, lentil, mungbean, broccoli and red cabbage ranges from 3.9 to 44.5 μmol Trolox/g and 0.7 to 2.4 μmol TE/g, respectively. γ-Tocopherol, primary isomer of vitamin E, is present in radish and small radish seed in concentration of 0.457 and 0.627 μmol/g, respectively (Zielinski et al. 2007). TPC of small radish and radish seeds was 15.01 and 18.7 μmol CE/g, while they show 40.8 and 48.6 μmol Trolox/g of antioxidant activity, respectively (Zielinski et al. 2007).

Studies on phytochemical properties of China-grown radish seeds showed that TPC and TFC in nine radish seeds varies from 9.15 to 14.54 mg GAE/g and 0.51 to 1.36 mg CE/g, respectively (Qian et al. 2017). Proanthocyanidins content in the seeds varies from 0.74 to 1.15 mg CyE/g. Total free phenolic acids in the nine radish seeds grown in China vary from 23.18 to 70.09 mg/g. Ferulic acid predominates in phenolic acid and ranges from 20.18 to 47.75 mg/g, followed by syringic acid (1.90–6.94 mg/g), sinapic acid (2.82–3.78 mg/g) and vanillic acid (0.46–18.77 mg/g) among different radish seed varieties (Qian et al. 2017). Among these, vanillic acid was not quantified in seeds of white round variety and hybrid 63 varieties, while Yanzhi 2 seeds showed highest vanillic acid content. Yanzhi 2 seeds do not have sinapic acid, and syringic acid was also absent in hybrid 63 seeds (Qian et al. 2017). Seeds of China-grown radish cultivars also possess significant amount of δ-tocopherol (552.24–670.16 μg/g) and lutein (4.82–8.98 μg/g). The DPPH scavenging antioxidant activity among China-grown radish seed extracts varies from 14.84 to 26.35 μmol TE/g, while the ORAC and reducing FRP of the seed extracts varies between 16.67 and 36.32 μmol TE/g and 0.75 and 1.04 μmol TE/g, respectively.

### 11.2.5 Peels

Radishes are mostly peeled before consummation, and these result in loss of many vital phytochemicals through peel waste. Tatsuzawa et al. (2008) stated that peel of red radish is a rich source of anthocyanins that include pelargonidin 3-sophoroside-5-glucoside, pelargonidin 3-[2-(glucosyl)-6-(trans-p-coumaroyl)-glucoside]-5-glucoside, pelargonidin 3-[2-(glucosyl)-6-(trans-feruloyl)-glucoside]-5-glucoside, pelargonidin 3-[2-(glucosyl)-6-(trans-p-coumaroyl)-glucoside]-5-(6-malonylglucoside) and pelargonidin 3-[2-(glucosyl)-6-(trans-feruloyl)-glucoside]-5-(6-malonylglucoside) as the main anthocyanin's pelargonidin pigments in the peel. Other than these pelargonidin 3-O-[2-O-(b-D-glucopyranosyl)-6-O-(trans-caffeoyl)-b-D-glucopyranoside]-5-O-(6-O-malonyl-b-D-glucopyranoside) and pelargonidin 3-O-[2-O-(b-D-glucopyranosyl)-6-O-(cis-p-coumaroyl)-b-D-glucopyranoside]-5-O-(6-O-malonyl-b-D-glucopyranoside) also contribute to the anthocyanin content of the peel (Tatsuzawa et al. 2008).

Peel of black radish exhibits strong antioxidant activities, and it shows antioxidant activities of 172.9 mg TE/g, 462.72 mg TE/g and 796.51 mg TE/g for CUPRAC, DPPH and FRAP assays (Yücetepe et al. 2020). The polyphenolic extract for black radish peel has TPC of 305.51 mg GAE/g and TFC of 171.58 mg CE/g. They also reported that bio-accessibility of TPC and TFC in the post-intestine phases was significantly higher in comparison to post-gastric. Similarly, antioxidant bio-accessibility was also higher in the post-intestine phases than in post-gastric phase. Peel of black radish is potential source of different phenolic compounds and flavanoids, which includes epicatechin, protocatechuic acid, ethyl protocatechuate, epigallocatechingallate, 4-hydroxybenzoic acid, vanilin, gallic acid, ferulic acid, chlorogenic acid, p-coumaric acid, sinapic acid, syringic acid and t-cinnamic acid. Among these, ferulic acid (28.02 mg/g) predominates the phenolic acids followed by epicatechin (19.82 mg/g), sinapic (11.15 mg/g), gallic (7.32 mg/g), chlorogenic (3.3 mg/g), 4-hydroxybenzoic (2.16 mg/g) and syringic acid (2.02 mg/g). Black radish peel also contains betaxanthin pigment (22.5 mg/100 g) and betacyanin pigment (7.7 mg/100 g) as Betalains with no detection of anthocyanins (Yücetepe et al. 2020).

Kuppusamy et al. (2020) found that radish peel has significant amount of bioactive components, having TPC of 31.3 mg GAE/g and TFC of 4.8 mg QE/g. Antioxidant potential of ethanol extract of radish peel as %DPPH inhibition was 72.8%, reducing power of 19.8 OD and vitamin C content of 48.8 mg AAE/g. The radish peel also contains heterocyclic aldehydes such as furfural along with 3-dicarboxylic acid such as dimethyl esters of propanedioic acid, butanedioic acid and dimethyl-dl-malate. They also reported that solvent used for bioactive compounds extraction significantly influence the content of compounds extracted with each solvent. Sarwari et al. (2019) also reported that among agro-wastes of vegetable, the peel of radish exerts significant antioxidant properties. The antioxidant activity as DPPH scavenging activity in the radish peel was found to be 52.70% and TPC of 43.82 mg GAE/g. Syringic acid (234.55 ppm) is the abundant phenolic acid found in the peel, followed by chlorogenic acid (127.12 ppm), gallic acid (115.12 ppm) and p-coumaric acid (78.31 ppm). Ferulic and vanillic acid were also found in concentration of 43.53 and 27.12 ppm, respectively (Kuppusamy et al. 2020). Dixit and Kar (2009) in their study reported that peel of radish contains 41.21 mg GAE/100 g of total polyphenols and 8.10 mg QE/100 g of flavanoids.

### 11.2.6 Flower and Pods

Pocasap et al. (2017) found that flowers of radish contain higher amount of isothiocyanates in comparison to other parts. They reported that both sulphoraphane and sulphoraphene were present in the radish flowers in the concentration of 18.73 μg/mg and 371.40 μg/mg, respectively. They also reported that the pods of radish contain higher amount of sulphoraphene (145.50 μg/mg) than sulphoraphane

(6.28 μg/mg) (Pocasap et al. 2017). Sangthong and Weerapreeyakul (2016) also reported that pod of radish is a potential source of isothiocyanates, and it has 2253.05 μg/g of sulphoraphene and 111.94 μg/g of sulphoraphane. Ali and Naz (2017) in their study reported that fully ripe radish pods are good source of bioactive components and antioxidants in comparison to unripe pods. They observed that fully ripe radish pods have phenolic content of 6.395 mg GAE/g, while unripe pods have 1.51 mgGAE/g. Similarly, the ripe radish pods have TFC of 2.58%, while unripe pods contain 1.79% of TFC. Antioxidant activity of mature radish pods is 6.59 mg/ml $IC_{50}$, while for unripe pods it was 3.15 mg/ml $IC_{50}$. They found that among different peels and pulps of 12 vegetables consumed in Pakistan, mature radish pods showed highest phenolic content. The petioles and flower of red radish are rich source of anthocyanins, and pelargonidin 3-sophoroside-5-glucoside, pelargonidin 3-[2-(glucosyl)-6-(trans-p-coumaroyl)-glucoside]-5-glucoside, pelargonidin 3-[2-(glucosyl)-6-(trans-feruloyl)-glucoside]-5-glucoside, pelargonidin 3-[2-(glucosyl)-6-(trans-p-coumaroyl)-glucoside]-5-(6-malonylglucoside) and pelargonidin 3-[2-(glucosyl)-6-(trans-feruloyl)-glucoside]-5-(6-malonylglucoside) are the main anthocyanins present in them (Tatsuzawa et al. 2008). Other than these, pelargonidin 3-O-[2-O-(b-D-glucopyranosyl)-6-O-(trans-caffeoyl)-b-D-glucopyranoside]-5-O-(6-O-malonyl-b-Dglucopyr-anoside) and pelargonidin 3-O-[2-O-(b-D-glucopyranosyl)-6-O-(cis-p-coumaroyl)-b-D-glucopyranoside]-5-O-(6-O-malonyl-b-D-glucopyranoside) also contribute to the anthocyanins content of the peel (Tatsuzawa et al. 2008). p-Coumaroyl is the primary anthocyanins pigment found in radish flowers.

### 11.2.7 Seed Sprouts

Radish seed sprouts are potentially good source of bioactive components, and their level in sprouts is much higher than other botanical fractions of radish. Barillari et al. (2006) in their study reported that the 6 days old freeze-dried sprouts of Kaiware Daikon extract (KDE) contained both glucosinolate of redox couple glucoraphasatin (GRH) (230 $\mu$mol/g dw) and glucoraphenin (GRE) (59 $\mu$mol/g). TPC in the 6-day-old seed sprouts was found to be 0.62 mg/L GAE. Hanlon and Barnes (2011) in their study reported that antioxidant activity of 7-day sprouts from eight different skin-coloured radish varieties was significantly higher in comparison to their mature taproots. The antioxidant activity in terms of FRAP for eight radish seed sprout varieties varies between 35.7 and 66.2 $\mu$mol AA Equiv/g, and the ORAC values were in the range of 202–275 $\mu$mol TE/g. Variation in the antioxidant activities were primarily due to the presence of colouring compounds and variation in the anthocyanin, glucosinolate and isothiocyanate in the sprouts. The TPC of 7-day-old sprouts from eight different radish cultivars varies between 15.6 and 24.2 $\mu$g GAE/g, while only red meat radish cultivar sprouts showed anthocyanin content of 0.29 mg/g of cyanidin-3-glucoside equivalents; however, the mature roots exhibit significantly higher anthocyanin contents in comparison to the sprouts (Hanlon and Barnes 2011). Sprouts are potentially good source of glucosinolate and isothiocyanate, and their level in sprouts is much higher than their mature taproot parts. Study of Hanlon and Barnes (2011) also reported that glucosinolate content in the radish sprouts of eight different cultivars lies between 76.9 and 133.9 $\mu$mol/g, and the content of isothiocyanate is between 20.0–77.6 $\mu$mol/g. They found that glucoraphasatin was the predominant glucosinolate present in the sprouts followed by glucoraphenin. The other glucosinolate present in the sprouts were glucoerucin, glucobrassicin, 4-OH glucobrassicin, and 4-OHMe glucobrassicin.

Seeds sprout of Kaiware Daikon radish exhibits significant antioxidant properties in terms of DPPH and $H_2O_2$ radical scavenging activity, and this AOA was basically due to the isothiocyanate than glucosinolate (Papi et al. 2008). When compared with different commercially used vegetables in Japan such as cabbage, pak-choi, capsicum, sweet pepper, spinach, garlic sprout and asparagus, radish sprouts exhibit significantly higher antioxidant properties using bleomycin-Fe method (Takaya et al. 2003). Methanol, hexane and 1-butanol extracts of the radish sprouts had methyl linolenate, linolenic acid, phytol, methyl sinapate, 1,2-disinapoyl-*â*-D-glucopyranoside, *â*-D-(3,4-dipinapoyl) fructofuranosyl-R-D-(6-sinapoyl) glucopyranoside, 1-*O*-(6″,9″,12″,15″-octadecateraenoyl)-3-*O*-*â*-D-galactopyranosyl glycerol, 1-feruloyl-*â*-D-glucopyranoside, 1-sinapoyl-*â*-D-glucopyranoside and *â*-D-(3-sinapoyl)-fructofuranosyl-R-D-(6-sinapoyl) glucopyranoside as bioactive compounds, which exert antioxidant activities that range between 0.4 and 2.7 in comparison to ascorbic acid (Takaya et al. 2003). Among these sinapic acid, ester was the prime constituent of the compounds.

Matera et al. (2012) in their study reported that sprout juice of radish contains 77.8 μmol/g of total isothiocyanates and 20.7 μmol/g of free isothiocyanates. Sprout juice also contain 8.9 μmol/g of E-raphasatin, 0.11 μmol/g Z-raphasatin and 11.7 μmol/g of sulphoraphene. The sprouts of radish also contained acylated anthocyanins (34 mg/g), which is significantly higher in comparison to sprouts of other cruciferous seeds and even more than red onion. Matera et al. (2012) also reported that radish sprouts contain total of 70 different anthocyanins and 19 of them are not discussed earlier. As per their study, the most predominant anthocyanins present in the sprout juice are cyanidin-3-sinapoyl-feruloyl-diglucoside-5-malonyl-diglucoside and cyanidin-3-feruloyl-sinapoyl-diglucoside-5-glucoside.

Radish sprouts exhibit significantly higher antioxidant properties and higher levels of TPC in comparison to the seeds and mature roots of the radish (Bors et al. 2015). The antioxidant property and TPC also vary with the seed colour and variety and sprouting time. The antioxidant activity of 3-day-old sprouts of red, white and black radish seeds are 60.71%, 58.10% and 63.80%, which then increased to 65.27%, 60.27% and 75.11%, respectively, after 5 days of sprouting (Bors et al. 2015). Further increase in sprouting time to 7 days decreased the antioxidant values in all the radish seeds, with final values of 60.72%, 53.6% and65.36% for red, white and black seed sprouts, respectively. Bors et al. (2015) found that TPC in 3–7 days old red radish sprouts varies between 15.45 and 16.94 mg GAE/g, 14.41 and 15.64 mg GAE/g in white radish seeds and 16.18 and 19.44 mg GAE/g in black radish seeds. Their results revealed that TPC depends much on the seed colour and the sprouting time.

The total phenolic content in radish sprouts was 12.5 mg GAE/g, which were significantly higher when compared with sprouts of broccoli, sunflower and mungbean as reported in the study of Pajak et al. (2014). Their study also reported that radish sprouts exhibit total flavanoids content of 34.8 mg QE/g while was significantly lower in comparison to sprouts of sunflower (45.6 mg QE/g) and broccoli (37.1 mg QE/g). Radish sprouts has highest antioxidant activity in comparison to broccoli sprouts and sunflower sprouts. AOA in terms of ABTS and FRAP for the radish sprouts was 24.67 mgTrolox/g and 104.9 mmol $Fe^{2+/}$/100 g, respectively, while the AOA in terms of DPPH is 6.07 mg TE/g (Pajak et al. 2014). The total free and bound phenolics and flavanoids in the sprouts of radish are 20.32 and 971 mg/100 g and 7.19 and 5.14 mg/100 g, respectively. Among bound phenolics, ferulic acid (13.50 mg/100 g) predominates followed by gallic acid (3.85 mg/100 g), caffeic acid (3.78 mg/100 g) and p-coumaric acid (3.11 mg/100 g) (Pajak et al. 2014). The free phenolic acid present in the radish sprouts are caffeic acid (9.61 mg/100 g), which is most predominant, followed by gallic acid (5.29 mg/100 g), protocatechuic acid (3.34 mg/100 g) and p-coumaric (1.21 mg/100 g) with smaller amounts of ferulic and sinapic acids (Pajak et al. 2014). Quercetin (7.09 mg/100 g) is the most predominant free flavanoid present in radish sprout (Pajak et al. 2014), with little amount of kaempferol, while in bound fraction luteolin (3.39 mg/100 g) is the most predominant flavanoid present followed by quercetin (1.38 mg/100 g) and kaempferol (0.37 mg/100 g)

Martinez-Villaluenga et al. (2010) found that both total and individual glucosinolates were significantly influenced by germination time and cultivars studied. They observed that germination brought a significant reduction in the total and individual glucosinolates in comparison to their respective seeds. Total glucosinolates in 3-day-old Rebel and Bolide cv. radish sprouts was found to be 101.96 and 45.89 μmol/g, respectively, which first significantly increased to 143.46 and 62.64 μmol/g in both the cultivars after 3 days and then decreased to 143.12 and 45.55 μmol/g after 5 days of sprouting in both the radish cultivars, respectively. The antioxidant activity in 3-day-old radish sprouts was 138.48 μmol Trolox/g for rebel radish cv, and 203.11 μmol Trolox /g in Bolide cv. The antioxidant activity was then significantly increased to 149.06 and 321.01 μmol Trolox /g in 4-day-old sprouts, and then finally decreased to 147.49 and 153.87 μmol Trolox/g in 5-day-old sprouts in both the cultivars, respectively (Martinez-Villaluenga et al. 2010). Raw seeds do not have any vitamin C, while it was synthesized during grain germination. Vitamin C content in 3-day-old sprouts of radish cultivars Rebel and Bolide was 25.09 and 61.63 mg/100 g, respectively, which was further enhanced to 83.98 and 113.34 mg/100 g in 5-day-old sprout of both the radish cultivars, respectively (Martinez-Villaluenga et al. 2010).

Radish sprouts exhibit antioxidant activity of 3.7 μmol Trolox/g for DPPH assay, 77.4 μmol Trolox/g for FRAP assay, and 3.3 μmol Trolox/g for ORAC assay, which were significantly higher in comparison to raw radish seeds (Aguilera et al. 2015). When compared with germinated seeds of alfa alfa, lentil, mungbean, onion, broccoli and red cabbage, Aguilera et al. (2015) observed that germinated seeds of red cabbage and broccoli exhibit significantly higher antioxidant activities in comparison to germinated radish seeds. They also found that germinated radish had TPC of 20.4 mg GAE/g, total catechin content of 0.3 mg CAE/g, total proanthocyanidins content of 0.4 mg Cl Cyanidin/g and melatonin content of 536.3 pg/g, which were significantly higher in comparison to raw seeds. When compared with sprouts of alfa alfa, lentil, mungbean, onion, broccoli and red cabbage, Aguilera et al. (2015) observed that sprouts of red cabbage exhibit significantly higher values for total phenolic and melatonin content in comparison to germinated radish seeds.

Zielinski et al. (2007) in their study found that 7-day-old sprouts of radish had α-, β- and γ-tocopherol content of 0.229 μmol/g, 0.059 μmol/g and 0.263 μmol/g, respectively. They also reported that sprouting of seeds brought a significant increase in the antioxidant activities, TPC and vitamin C contents. They found that 7-day-old sprouts of small radish and radish exhibit TPC of 36.5 and 34.6 μmol catechin/g, antioxidant activity of 84.5 and 72.0 μmol TE/g, vitamin C content of 31.8 and 23.0 μmol/g, respectively. Ghoora et al. (2020) in their study found that microgreens of radish seeds are potential source of bioactive components. They found that radish microgreens possess 114.4 mg/100 g of ascorbic acid, 10.7 mg/100 g of lutein, 61.8 mg/100 g of total phenolics, 50.9 mg/100 g of total chlorophyll and 2.1 mg/100 g of total flavanoids. Antioxidant activity in terms of DPPH $IC_{50}$ was 155.7 μg/ml, while it was 22.7 μmol $Fe^{2+/}$g for FRAP assay and 15.4 μmol TE/g for TEAC ABTS assay. Yuan et al. (2010) inform that total glucosinolates content in 3-day-old radish sprouts were 14.67 μmol/g, which increased with increase in sprouting period; however, the content increased with increase in the salt concentration in the growing medium. The 3-day-old radish sprout contains 0.25 μmol/g of 4-OH-glucobrassicin, 14.28 μmol/g of glucoraphasatin, 0.05 μmol/g and 0.09 μmol/g of glucobrassicin and 4-methoxyglucobrassicin, respectively. Total phenolic content in 3-day-old sprouts was 75 mg GAE/100, which decreased with increase in salt concentration and sprouting time (Yuan et al. 2010). The antioxidant activity in 3-day-old radish sprout was 16.12 mmol/100, which decreased with increase in sprouting time, while slat concentration of 100 mM enhances the antioxidant activity of the sprouts in comparison to control.

## 11.3 Antioxidant Properties of Products Prepared from Radish

Li et al. (2020) in their study reported that pickled radish contains 2,6-dihydroxyacetophenone, 4-hydroxybenzaldehyde and 4-hydroxyphenethylalcohol phenolic compounds. Among these compounds, 2,6-dihydroxyacetophenone showed highest antioxidant activity (DPPH) of 66.21%, followed by 4-hydroxyphenethylalcohol. Similarly all these compounds also exhibit good AOA in terms of ABTS assay, while in terms of reducing power, the antioxidant activity was not much, and it was highest in 2,6-dihydroxyacetophenone (0.188 mM Trolox) with antioxidant capacity of 0.752 mM/g. Bao et al. (2016) reported that pickled radish contains two isothiocyanates that are 1-isothiocyanato-2-methylpropane (0.10) and 2-isothiocyanato-2-methylbutane (0.09), with 2,2,4-trimethyl-3-oxabicyclo[2.2.2] octane (12.11), 3,7-dimethylocta-1,6-dien-3-ol (11.92), terpenes (7-methyl-3-methylideneocta-1,6-diene) (2.11), aldehydes (0.22) and sulphoether compounds such as 3-methylsulphanylprop-1-ene, (methyldisulphanyl) methane, 3-prop-2-enylsulphanylprop-1-ene, 3-(prop-2-enyldisulphanyl)prop-1-ene, which give the pickled radish their characteristic aroma and flavour and exhibit antioxidant properties. Salted radish, a tradition Japanese food, contains 4-methylthio-3-butenyl isothiocyanate, which generates yellow pigment in the product and when reacts with water forms a 1-(2-thioxopyrrolidin-3-yl)-1,2,3,4-tetrahydro-b-carboline-3-carboxylic acid that being unstable at pH 7 was simply transformed to 2-[3-(2-thioxopyrrolidin-3-ylidene)methyl]-tryptophan, a novel yellow pigment in Japanese salted radish (Matsuoka et al. 2002). Takahashi et al. (2015) reported that this novel yellow compound possess antioxidant properties as higher levels of this compound improves the free radical scavenging potential in the product. Vitamin C content in fresh cut radish roots is 19.89 mg/100 g, which can be decreased when stored at refrigeration temperature; however, when treated with different antioxidants, its ascorbic acid was enhanced, which retained well during 10 days of storage. Rodriguez-Saona et al. (2001) reported that concentrate from the red radish is a rich source of anthocyanins and contain 400 mg/100 ml of the concentrate at 17 $^{o}$B, and this concentrate can be used as an alternative to FD&C Red #40 colour in food and pharma applications.

## 11.4 Chemical Compound(s) Responsible for Antioxidant Properties and Biological Activities

The leaves are good source of phenolic acids that include hydroxycinnamic acid compounds, hydroxybenzoic acid derivatives, catechin, myricetin, quercetin, caffeic protocatechuic, syringic, vanillic, ferulic, sinapic, *p*-coumaric, salicylic and gentisic acid. Flavanoids present in the leaves are kaempferol, quercetin and rutin. Glucosinolates such as 3-indolylmethylglucosinolate, 4-methoxy-3-indolylmethyl-glucosinolate and 4-hydroxy-3- indolylmethyl-glucosinolate are present. 4-Methylpentyl isothiocyanate, 5-(methylthio)-4-pentenenitrile, 4-(methylthio) butyl isothiocyanate erucin, 2-phenylethyl isothiocyanate, 4-(methylthio)-3-butenyl isothiocyanate, benzenepropanenitrile, 3-(methylthio)propyl isothiocyanate, benzyl isothiocyanate and 2-phenylethyl isothiocyanate are main isothiocyanates present in the leaves. Seeds of radish primarily contain glucosinolates, brassinosteroids, alkaloids and flavonoids. 4-hydroxy-3-indolylmethyl glucosinolate and 4-methylsulphinyl but-3-enyl glucosinolate are the glucosinolates present in radish seeds. Hexyl isothiocyanate, 4-methylthiobutyl isothiocyanate, 4-methylpentyl isothiocyanate, 4-methylthio-(3 *E*)-butenyl isothiocyanate, 4-methylthio-(3*Z*)-butenyl isothiocyanate and isoamyl isothiocyanate are the isothiocyanates present in seeds. In the seed sprouts, 4-hydroxy-3-indolylmethyl glucosinolate, 4-methoxy-3-indolylmethyl glucosinolate, 3-indolylmethyl glucosinolate and 4-methylthio-3-

butenyl glucosinolate were present as major glucosinolates. Glucoraphenin (4-methylsulphinyl-3-butenyl Gs, glucoraphenin) and glucoraphasatin (4-methylthio-3-butenyl Gs, glucoraphasatin) are also present in seed sprouts. The phenolic acids present in seed sprouts are chlorogenic, vanillic, caffeic, syringic, *p*-coumaric, ferulic, gallic, protocatechuic and *p*-hydroxybenzoic acids. Pelargonidin, delphinidin and cyanidin were the main anthocyanins present in the various coloured radish taproots. The acylated (di- and mono-acylated) anthocyanins based on pelargonidin 3-sophoroside-5-glucoside, acylated with feruloyl, caffeoyl or *p*-coumaroyl groups are present in radish. Different acylated anthocyanins based on cyanidin 3-(glucosylacyl) acylsophoroside-5-diglucosides, 3-sophoroside-5-diglucosides, 3-sophoroside-5-glucosides, 3-sophoroside-5-diglucosides and 3-sophoroside-5-malonylglucosides are also found in radish.

## 11.5 Health Benefits

All the botanical fractions of the radish, which include roots, peel, stem, leaves, flowers, and pods and seeds possess various bioactive components that are related to various health benefits. Juice of radish leaves and roots are traditionally used to cure diarrhoea, urinary problems, gastro pains and gastric alignments, owing to their antiscorbutic, diuretic and laxative effects (Stuart 2013). Radish roots are also used to treat fever, burns, scalds or smelly feet. In the traditional Chinese, South Asian, Mexican medicines, radish is used to cure kidney stone, gall bladder stone, whooping cough, gastrointestinal disorders, hepatic diseases and for lowering blood serum levels (Zhang et al. 2010; Ghayur and Gilani 2012; Castro-Torres et al. 2012, 2014). Bioactive compounds and their antioxidant activities (see chemical compounds section) present in the different botanical fraction of the radish possess various health-promoting activities such as antimicrobial (Aerts et al. 2007, 2009; Beevi et al. 2009; Ahmad et al. 2013; Janjua et al. 2013), anticancer (Lee and Lee 2006; Barillari et al. 2008; Beevi et al. 2010a, b, c; Kim et al. 2011, 2014; Salah-Abbès et al. 2010b), anti-mutagenic (Nakamura et al. 2001; Salah-Abbès et al. 2009c), antidiabetic (Taniguchi et al. 2006, 2007; Shukla et al. 2011), anti-inflammatory (Sipos et al. 2002; Kim et al. 2014; Kamble et al. 2013), spasmogenic (Gilani and Ghayur 2004; Ghayur and Gilani 2012), hepatoprotective (Mohammed et al. 2008; Salah-Abbès et al. 2008, 2009b; Lee et al. 2012), enzyme detoxification (Hanlon et al. 2007, 2009; N'jai et al. 2012), antihypertensive (Ghayur and Gilani 2006; Li et al. 2007; Chen et al. 2007), antiatherosclerotic (Suh et al. 2006), antiviral (Prahoveanu and Eşanu 1990), immunoprotective (Salah-Abbès et al. 2008, 2010a, 2015), antilithiatic and diuretic (Castro-Torres et al. 2014), choleretic (Barillari et al. 2006), gastroprotective (Algasoumi et al. 2008), antidiarrhoeal (Zhang and Shen 1996), skin anti-ageing and skin whitening (Jakmatakul et al. 2009; Roh et al. 2013), reproductive toxicity protective (Salah-Abbès et al. 2009a), laxative (Dande et al. 2014), antilipase (Thomson et al. 1997; Zheng et al. 2010), antitussive (Tan et al. 2005) and antithyroid activity (Chandra et al. 2004, 2006).

## 11.6 Conclusion

Radish is a cool-season crop comes in red, white and yellow colour and in various sizes and shapes. It is primarily cultivated for its taproots and is consumed worldwide, particularly in Asian countries as fresh, salad or in the form of juice. Each botanical fraction of radish be it its root, leaves, seeds, seed sprouts, pods, flowers, peel and stem have diverse range of bioactive molecules providing great benefits to the human health. Radish is a good source of antioxidant owing to presence of diverse range of phenols, flavanoids, anthocyanins, glucosinolates and isothiocyanates. Radish leaves possess higher levels of bioactive compounds in comparison to mature taproot. The presence of bioactive components in various fraction of radish exerts various health-promoting activities such as anticancer, antibiabetic and antihypertensive activities. Being a powerhouse of various phytochemicals, radish and its various parts are not available in the processed form in the market, and hence, further research is required to explore the potentiality and applications of this wonder root crop in processed food products to study the fate of the bioactive compounds during processing.

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# Dandelion

# 12

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**Abstract**

Dandelion is prominently known as a weed. Several records have revealed its existence to live on a global basis. Dandelion acts as an excellent diuretic as well as blood and liver cleanser. It imparts numerous health benefits such as protection from ailments such as anaemia, liver cirrhosis and rheumatism apart from acting as potent anticancerous and anti-coagulatory agent. It grows on temperate regions of the world, along the roadsides, banks and prominently in areas with damp soils. The leaves of dandelion have received tremendous attention from researchers owing to the various chemical and pharmacological properties exhibited by them. It works as a folk medicine for the treatment of boils, fever and sore throat.

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Dandelion has shown widespread adaptability by surviving in manifold conditions. It has been also reported to exhibit anti-inflammatory and antioxidant properties which are attributed mainly to phenolics that are mainly more concentrated in the leaves than in the roots. There is sufficient data which have highlighted the significance of extracts from various species of dandelion such as *Taraxacum officinale*, *Taraxacum coreanum* and *Taraxacum mongolicum* to be utilized as an anti-inflammatory.

**Keywords**

Dandelion · Antioxidant activity · Anti-inflammatory · Anticancerous · Health benefits

**Botanical name/common name –** *Taraxacum officinale/*dandelion

## 12.1 Introduction

The word 'dandelion' is derived from the French term 'dent de lion', which means teeth of the lion, signifying the teeth-shaped edges of the leaves (Yarnell and Abascal 2009). Plant historians believe that the nativity of dandelion is shared between the Mediterranean section along with ancient Greeks, Romans and Egyptians (Abulafia 2011). Persians identified dandelion as tarashquq around 900 AD. After a few decades, the name got altered to taraxacum. The common name of this plant is based on the petals of the flower which resemble the canines of a lion, which in French is translated as 'dents de lion' and later modified as 'dandelion' (Allaby 2010). The earliest discovery of dandelion took place in North America with the Vikings (Stewart-Wade et al. 2002).

Dandelion is recorded to have its fossil seeds in Places of south Russia. The first ever documented records of dandelion are between the tenth and eleventh centuries by ancient Romans and Anglo-Saxons followed by the Europeans during the thirteenth century (Coates 2013). Between the tenth and eleventh centuries, dandelions are mentioned for medicinal objectives by Arabian physicians. The ethnic population of North America also utilized dandelion in their conventional therapeutic procedures. Being a common plant, dandelion is observed widely around, and in India, it was observed in the Himalayas and has been used for its herbal potential against liver disorders and as diuretics (Tabassum et al. 2010). Dandelion has gathered exciting labels all through the past including 'pee in the bed', 'swine snout' and 'witch's milk' for their diuretic property. Greek botanist Theophrastus between 371 BCE and 287 BCE has suggested dandelion's tonic, particularly to fight blotches and liver-coloured freckles on the skin surface (Mars 2016). Persian physician, theorist and researcher Abu Ali Sino, well-known as Avicenna, testified that milk extract from dandelion retains positive impacts in lessening the signs of glaucoma (Sharifi-Rad et al. 2018). Dandelion is additionally designated as a plant with high medicinal values by Ortus Sanitatis in 1485 at European herbal. Meanwhile, throughout both the world wars, it was a resource of nutrition, while several individuals experienced nutritive inadequacies. Since 1930, studies about dandelion have been concentrated on the assessment of its pharmacological potential and biochemical characteristics on human biology (Martinez et al. 2015). Dandelion retained a position in the United States National Formulary from 1888 to 1965, and the dried up root of dandelion plant is recorded in the United States Pharmacopoeia.

### 12.1.1 Production (India, World)

Dandelion being an edible plant has its widespread abundance in the temperate zones with warm climate of the northern hemisphere (Jinchun and Jie 2011). Dandelions grow well on lands high in nitrogen and potassium. Also, lands low in calcium or soil with inadequate decomposition of organic material are suitable for the growth of this crop (Kuusi et al. 1984). They are herbaceous crops that grow well in humid, warm regions observed in more parts of the northern temperate region and also have the ability to survive in a variety of climates. On the contrary, dandelion cannot be cultivated on soils rich in phosphorus.

Dandelion is regularly cultivated by relocating and is uniformly spread out in rows since it occupies more space while growing (Martin and Leonard 1949). This also facilitates the seedlings to be less competitive with the already emerged crops. Being a perennial wildflower, dandelion creates a sturdy taproot with a usual length of up to 15–30 cm. Immature dandelion shoots are planted and bedded into compost soil (Petlevski et al. 2003). The blooms grow up from the highest vicinity of the root where a stiff crown is created. The roots of dandelion plant have several hairlike rootlets. Though the dandelion is cut back beneath the soil surface, the residual tubers will be able to produce new plants. Generally, an average of 14,000–15,000 seeds will be generated per dandelion plant. The seeds per flower range between 150 and 200 in numbers, and up to 10 flowers can be cropped out per plant (Bretzel et al. 2014).

For large scale production of dandelion's leaves, they are frequently grown-up as a transplant and are placed in uniformly spaced rows. To produce roots, dandelion sowing is done directly in the first part of spring. Roots are of their finest quality and size at about 2 years' post-sowing period (Eggert et al. 2018). All sections of the plant are consumable and are utilized for therapeutic and culinary objectives. The roots and leaves can be dried up and processed for use therapeutically, the blooms can be produced into dandelion wine, and the young leaves can be consumed fresh in salad, while the matured ones are used in cooking (Tierra 1998).

The initial evidences related to the origin of dandelion pertain to Europe, Asia and North America which leads to the difficulty in determining its exact indigenous environment (Tarlo 2017). Dandelion is one of those plants with immense medicinal attributes which is grown and cultivated naturally in Europe, North and South America and Asia (Qureshi et al. 2017). The distribution of dandelion is observed in Central and South America along with Australia as well as New Zealand (Mingarro et al. 2015). The most prominent reasons for its production are for medicinal uses as well as for food applications (Wirngo et al. 2016). Dandelion was also used by North Americans, Ojibwa and Rappahannock tribe for medicinal purposes on traditional basis (Tarlo 2017). The major countries which are known for the cultivation and production of dandelion are Bulgaria, Romania, Hungary and Poland (Brock 2004). The common areas where dandelion can be traced out lie in the tropics, in highlands having altitudes and cool climate and in temperate zones with hot climate in the northern hemisphere (Wirngo et al. 2016).

### 12.1.2 Botanical Description

*Taraxacum officinale* is a milk-conveying perennial herb lacking stem. It is considered as a herb from the family Asteraceae and tribe Lactuceae which can attain a height of 0.5 m (Bashmakov et al. 2008) or even 2 m (Stewart-Wade et al. 2002). The stems are extremely low in length (1.25 cm approx.) along with much shorter internodes located at or under the soil (Gier and Burress 1942). The leaves of dandelion show huge variations with respect to shape and colour with covering of hairs on the outer surface responding rapidly to water, nutrients and exposure. It has flowers with golden yellow colour embedded on empty stems emerging from the centre of the rosette (Fatima et al. 2018).

The leaves of dandelion are generally 5–40 cm and 0.7–15 cm in length and breadth, respectively, reducing in thickness towards the petiolar base with wings (Holm et al. 1997). The roots of dandelion become short in length and move deep inside the soil for protection (Ianovici 2016). Dandelion is stemless having extremely short internodes along with a roselike arrangement of leaves at the base region (Lis et al. 2018). The lateral roots in two different rows intertwine in a spiral fashion in a clockwise manner around the root with their distribution along the entire length (Gier and Burress 1942).

Dandelion has leaves which have deep teeth without hairs with a length of 5–30 cm and breadth of 1–10 cm (Fatima et al. 2018). It has a well-developed tap root system whose length goes up to 0.5 m (Bashmakov et al. 2008). The roots are brown on the outer side whereas white on the inner side with fleshy texture prone to breakage (Fatima et al. 2018). The flowers are capable of growing up to a diameter ranging between 7 and 15 mm (Tarlo 2017).

The fruit of dandelion closely looks like olive-brown achenes along with a white clump of fibres increasing the surface area resulting in flight (Bashmakov et al. 2008). The taproots of dandelion are dark brown in colour with a solid appearance which can go deep into the soil up to 10–15 feet (Hourdajian 2006).

## 12.2 Characterization of the Chemical Compound(s) Responsible for Antioxidant Properties

### 12.2.1 Bioactive Components and Their Antioxidant Properties

Diverse health benefits of dandelion are attributed to a wide range of bioactive molecules distributed in their tissues (leaf, flower, root, skin) which mainly include terpenes, flavonoids and phenolic compounds. Sesquiterpene lactones taraxacin and taraxacerin (Leung et al. 1996) impart bitterness to the plant. Triterpenoids like cycloartenol, taraxasterol and Ψ-taraxasterol are distributed in their tissues (Cordatos 1992). Flavonoid glycosides including luteolin 7-glucoside, luteolin 7-O-rutinoside, isorhamnetin 3-O-glucoside and apigenin 7-O-glucoside have been isolated and identified from its flowers and leaves using chromatographic methods, and the only quercetin 7-O-glucoside was identified from inflorescences and leaves (Fatima et al. 2018; Wolbis et al. 1993).

Additionally other sesquiterpenes, namely, tetrahydroridentin B and taraxacolide-*O*-β-glucopyranoside; the guaianolides 11β,13-dihydrolactucin and ixerin D; three germacranolide esters, taraxinic acid β-glucopyranoside, its 11,13-dihydroderivative and ainslioside; and various triterpenes, their acetates and 16-hydroxy derivatives were also identified (Kisiel and Barszcz 2000; WHO 2007; Gonzalez-Castejon et al. 2012). Hydroxycinnamic acids, chicoric acid, monocaffeyl tartaric acid and chlorogenic acid are prevalent in the plant, whereas the leaf extracts are a main source of coumarins, cichoriin and aesculin (Williams et al. 1996).

In addition to this, other terpene components such as beta-amyrin, free sterols, phenylpropanoids, triterpenoid saponins and polysaccharides such as fructosans and inulin were also identified. Complex carbohydrates such as pectin and resins were also identified. Williams et al. (1996) isolated and identified cinnamic acid, coumarins and flavonoids from *T. officinale* plant by using various analytical methods.

Diaz et al. (Díaz et al. 2018) examined the hexane extract and characterized lupeol acetate, betulin, lupeol, 3,7,11,15-tetramethyl-2-hexadecen-1-ol, diethyl phthalate and phytol. On the other hand, 80 components were identified in the ethyl acetate extract. Several studies have reported that the dandelion extracts showed potential antioxidative activity as examined in food and biological models with the antioxidant potential mainly associated with the substituted amount and position of hydroxyl groups (Teissedre et al. 1996; Hu and Kitts 2005; Liao and Yin 2000). Components responsible for this property are found to be ascorbic acid, flavonoids and coumaric acid. The extracts of the leaves have the potential enough to donate hydrogen and scavenge hydrogen peroxide as well (Hagymasi et al. 2000; Wolbis et al. 1993).

It was also reported that the leaf and root extracts of dandelion have hydrogen-donating, ROS formation-inhibiting and radical-scavenging activities. Another major study revealed that in the case of dandelion flower extracts, ethyl acetate fraction imparted protection to DNA from ROS-induced damage by scavenged ROS. Oxidative stress was also prevented due to the bioactive components such as luteolin and luteolin 7-O-glucoside (Hagymasi et al. 2000). Hu and Kitts (2005) reported the flower extracts of dandelion inhibited hydroxyl-radicals which was attributed to the phenolic components such as caffeic acid, chlorogenic acid, luteolin and luteolin 7-glucoside.

## 12.3 Health Benefits

In accordance with literature survey, *Taraxacum officinale* has been recognized for its medicinal and nutritive value due to the presence of several bioactive compounds such as terpenes, flavonoids, alkaloids, saponins, steroids and phenolic substances (Mir et al. 2013). Dandelion has been predominantly known to Asia, Europe and North America and is widely utilized in various conventional as well as current herbal medicines. The plant is incorporated in folk medicines of India, China and Russia for the treatment of various liver diseases and some female disorders such as uterine and breast cancer. In China, the therapeutic value of dandelion was combined with other herbs to cure hepatitis. The plant is also used to prevent respiratory tract infection, jaundice, toxicity, fever, eye problems, eczema, anaemia and pneumonia (Blumental et al. 2000; Mahesh et al. 2010).

The nutritional value of dandelion roots comprises of carbohydrates (inulin); vitamins; carotenoids (lutein); fatty acids (myristic acid); hexose sugars like glucose, sucrose and fructose; choline; mucilage; and pectin. About 45% of roots contained inulin, a fructo-oligosaccharide complex, which may be helpful in abolition of pathogens present in the gastrointestinal tract, suppression of obesity, prevention of osteoporosis and tumour regression (Roberfroid 1999). The leaf extracts are recognized to be highly effective against obesity and cardiovascular disorders (Choi et al. 2010).

In addition, dandelion is reported to be a storehouse of many bioactive compounds such as sesquiterpene, lactones, taraxerol, taraxasterol and chicoric and chlorogenic acids. These harmless and non-toxic components are reported to exhibit antioxidative, antidiabetic, anti-inflammatory, antirheumatic and chloretic activities (Arpadjan et al. 2008). The research work concerning the interesting components like taraxerol and taraxasterol is scanty, though these components are present in greater amounts in dandelion as compared to other plants (Sharma and Zafar 2014). It is also a rich source of many vitamins particularly vitamins A, C, E, D and B and minerals especially iron, zinc, copper, manganese, sodium, potassium, magnesium, calcium, silicon and phosphorous. Minerals like iron and calcium are found to be in higher concentrations as compared to that in spinach (Ali 1989; Ata et al. 2011). The mobility of ions like calcium may assist to arouse the exocytosis of insulin (Komatsu et al. 1997).

Dandelion is acknowledged as the richest source of β-carotene (11,000 μg/100 g leaves) which is almost equivalent to that carrot (Mir et al. 2015). In the study of Khoo et al. (2011), it was presented that β-carotene contained in dandelion provides protection against oxidation and cellular damage. More recently, chicoric acid, with polyphenolic content of $34.08 \pm 1.65$ g/Kg, is recognized as the most plentiful constituent of dandelion. The flowers and leaves are found to have greater concentration of polyphenolics in comparison to the stem (Williams et al. 1996; Fraisse et al. 2011; Kenny et al. 2015).

Among the common metabolic disorders, diabetes is characterized by high blood pressure; artery blockage; heart diseases; imbalanced carbohydrate, lipid and protein metabolism; and also abnormality in pancreas functionality (Mutalik et al. 2003; Abdul-Ghani et al. 2006). This metabolic disorder might occur due to imbalance in secretion as well as activity of insulin and glucagon hormones, which in turn may cause enhancement in plasma glucose levels and distraction of natural processes in the liver, pancreas, skeletal muscle tissue, adipose tissue, nervous system and gut. The interruption in natural phenomenon leads to irregularity in glucose homeostasis, which has significant role in the occurrence of this endocrine multifactorial ailment (Scheen 2003). Other symptoms of diabetes may include renal malfunctioning and blindness, which are most important risk factors for cardiovascular heart diseases.

Literature studies demonstrated that traditional medication including the utilization of bioactive plants can possibly mitigate diabetic side effects, empower recuperation and improve well-being (Marles and Farnsworth 1995). In spite of generous advancement in treatment of diabetes by oral hypoglycaemic agents, investigations for newer medicines proceed in light of the fact that the current synthetic drugs have a few constraints and destructive impacts. Natural drugs have been utilized and asserted as antidiabetic agents, yet exceptionally less are accessible on economically figured structures (Ghazanfar et al. 2014).

Nnamdi et al. (2012) evaluated the antidiabetic potential of dandelion leaf and root in streptozotocin (STZ)-induced diabetic rats. It was demonstrated that both roots and leaves exhibit hypoglycaemic effect, but the roots are reported to be more beneficial in treating diabetes. The antidiabetic potential of dandelion might be due to binding of tannins with amylase enzyme. This association reduces the digestive activity of amylase, and ultimately digestion of carbohydrates slows down, which results in lowering of glucose levels in blood. Tannins are also reported to have binding ability to glucose molecules, thus reducing their availability for absorption in blood (Thompson 1993).

The alpha amylase and alpha glucoside inhibition potential of dandelion was studied by Mir et al. (2015) for evaluating the antidiabetic activity. Methanol and water extracts of roots, stem and flowers parts of dandelion were considered. Results of the study revealed that water extracts possess significant alpha amylase and alpha glucoside inhibition potential and thus antidiabetic activity in comparison to methanol extracts. The highest antidiabetic property was exhibited by stem, while flowers possess the least antidiabetic activity. It was also documented that inulin, a fructo-oligosaccharide complex, existing in roots of dandelion is recognized for lowering hyperglycaemia as well as normalization of blood sugar levels. The mechanism for reducing hyperglycaemia might involve binding of inulin with the molecules of glucose, leading to increased glucose absorption after the digestion process (Yarnell and Abascal 2009).

The antimicrobial potential of dandelion leaves was demonstrated by Diaz et al. (2018). In their study, the phytochemical constitution and biological properties of n-hexane and ethyl acetate extracts of dandelion leaves were explored. Both extracts were reported to have significant amounts of triterpenoids and fatty acids mainly palmitic and linolenic acids. The results of the study propose that both extracts inhibit the activity of uropathogenic bacteria. Therefore, the dandelion leaf extracts could be utilized in the production of future products with industrial relevance.

The effectiveness of dandelion root extract against drug-resistant human melanoma cells was investigated by Chatterjee et al. (2011). They reported that root extracts are highly active in regression of chemo-resistant skin cancer cells without causing any toxicity to healthier tissue and proposed that dandelion can be regarded as novel and natural chemopreventive agent.

The anti-inflammatory activity of leaves of *T. officinale* is reported to provide protection against cholecystokinin-induced severe pancreatitis in rats (Seo et al. 2005). The various constituents such as terpenoids, taraxacin and taraxacerin found in *T. officinale* are known to prevent gall bladder and liver disorders (Wirngo et al. 2016).

During biological processes such as autoxidation, oxidative phosphorylation and glycosylation, higher glucose may produce reactive oxygen species (ROS) in β-cells (Robertson et al. 2007). The excess production of these reactive substances may enhance the risk of various diseases. To overcome the degenerative effects of these chemical species, the need of antioxidants becomes vital. Literature studies revealed that plant materials are blessed with compounds having high antioxidant activity and are regarded as best source of potentially safer natural antioxidants. According to You et al. (2010), dandelion is recognized to have sufficient antioxidative activity to provide protection against the highly reactive degenerative species. The leaf extracts are highlighted for their hydrogen-donating, $H_2O_2$ scavenging and reducing abilities. Flowers are also acknowledged for high antioxidant potential due to the existence of significant amounts of phenolic compounds such as flavonoids and ascorbic and coumaric acids. The radical-scavenging capability and hydrogen-donating power of root and leaf parts of dandelion were demonstrated by Hagymasi et al. (2000). They also conclude that roots and leaves can inhibit the formation of highly reactive oxygen species to a greater extent.

In accordance with available literature, *Taraxacum officinale* (dandelion) has been widely used as antimicrobial, antioxidant, diuretic and digestive and insulin stimulant. It can be recognized as chief antidiabetic plant as it exhibits hypoglycaemic, antioxidant and anti-inflammatory activities. The therapeutic value of dandelion might be attributed to the various bioactive compounds like triterpenes, polyphenolic substances, sesquiterpenes, phytosterols and the most significant chicoric and chlorogenic acids. The other health promising effects such as anticancer, antisteatotic, hepatoprotective and antilipidemic have also been recognized. However, further research work concerning the bioavailability as well as metabolism of dandelion constituents is scanty and requires to be explored.

## 12.4 Conclusion

The taxonomy of *Taraxacum officinale* is complex. Its origin lies in Europe. The major reasons for its production are aimed at medicinal and food applications. Apart from this, dandelion is also regarded as an antidiabetic due to its anti-hyperglycaemic and antioxidative potential. Owing to various bioactive components in dandelion such as phenolic compounds, triterpenes and phytosterols, this plant has been able to gather ample attention from the research world. It can withstand drought as well as frosty weather. Dandelion does not hold the potential to remain in medicinal history but also a promising plant to be explored in the future.

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# Drum Stick (*Moringa oleifera*) 13

Varun Kumar, Amarjeet Kumar, Gulzar Ahmad Nayik, and Syed Mansha Rafiq

**Abstract**

*Moringa oleifera* is a small- to medium-sized multipurpose tree, which grows in tropical and subtropical regions of the world. *Moringa oleifera* is drought-resistant, preferring regions with dry/wet climate and hence is cultivated in a wide range of habitats on a variety of soils across the world. It contains a significant value including as food, fodder, medicine, fuelwood, and fertilizer from all parts of the plant. Leaves are rich in minerals, vitamins, and other essential phytochemicals. These phytochemicals are used as conventional drugs for antioxidants, antitumor, antidiabetes, antihyperlipidemia, and as antimicrobial agents. The leaves extract is also involved in the treatment of malnutrition, augmenting breast milk in lactating mothers. The production of seeds from elongated capsule fruits is most useful in water purification. The scientific evidence provides insights on the utilization of *Moringa oleifera* to cure diabetes, cancer. The large-scale commercial cultivation of this species accelerates the medicinal, nutritional, and prominent pharmaceutical values.

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**Keywords**

Phenols · Quercetin · Free radicals · Superoxide species · Anticancer · Antidiabetes · Antioxidant · Antihyperlipidemia

## 13.1 Introduction

Our country has enriched culinary tradition which has helped us to relish and taste several types of vegetables and fruits and thus develop innumerable health benefits. One such remarkable vegetable which is significantly valued and which produces great interest is known as *Moringa oleifera*. It is a fast-growing plant worldwide and is cultivated to use as vegetable enriched with vital nutritional value and indispensable medicinal properties.

### 13.1.1 Taxonomic Classification

The taxonomical classification description of *Moringa oleifera* is the following:

Kingdom: Plantae
Division: Magnoliophyta
Class: Magnoliopsida
Order: Capparales
Family: Moringaceae
Genus: Moringa
Species: Oleifera

### 13.1.2 Synonyms

*Moringa oleifera* is recognized through numerous common terms such as drumstick tree, horseradish tree, cabbage tree, clarifier tree, ben oil tree, kelor tree, miracle tree, mother's best friend, never die, River Nile tree, West Indian ben, sajna (Hindi and Bengali), munuga (Hindi), saijihan, marango, shevaga (Marathi), murungai (Tamil), muringnga (Malayalam), and munagakaya (Telugu).

### 13.1.3 Description

*Moringa*'s name has been received from the Tamil word, murungai, which represents the twist pod. The humble vegetable is used widely in Indian culinary dishes for more than hundred years. *Moringa oleifera* renders its unique flavor to sambhar, avial, meat curry, soups, pickles, and other dishes. *Moringa*, a slender, deciduous tree, grows underground rootstock and single trunk in a wide size, with open and natural umbrella-fashioned crown to a height 10–12 meters and 10–45 cm diameter of the trunk and it is covered through pale gray bark, but sometimes it spreads 60–65 cm wide. The younger shoots have purplish/ greenish color, ciliary bark, and drooping, fragile branches. Leaves are arranged on petioles in alternative downy foliage. The leaves are tripinnate and generally 20–65 cm long but sometimes may be minor 6 cm long and large up to 90 cm. It bears small stalked glands on petiole basement and leaflets that exude a pure or amble-colored.

The inflorescence extensively scatters the axillary panicle as long as to 8–30 cm. The five unevenly aromatic flowers are surrounded, yellowish-white, and around 2.5 cm across.

The tree normally begins to flower after five to six months of the plantation. The flowering can happen twice or all-round the year in the seasonal climate with good rainfall.

The large elongated capsule seedpods, dark brown globular seeds are arranged on three sides by three whitish papery wings. The usual size of capsules is 19–50 cm long and 1–5 cm wide, but sometimes it is also recorded to be 10–90 cm long. Fruits are green during immature stage, but after mature stage, it turns to pale brown. When it has become fully mature, it is dehiscent and is split open via valves. The seed's color is dark brown or blackish, which is embedded in the fruit valve.

Every part of the tree is highly costly and consumed as a super food or traditional medicine. *Moringa* is abundant with nutrients and antioxidants which provide us with a plethora of wellness incentives. It is owing to the occurrence of different essential phytochemicals and nutrients in leaves and seedpods. *Moringa* has been reported to deliver vitamin-C 7 times more than orange, vitamin A 10 times more than carrots, calcium 17 times more than milk, protein9 times more than yogurt, 15 times more potassium compared to bananas, and 25 times more iron compared to spinach (Rockwood et al. 2013).

### 13.1.4 Nutritional Composition

The leaves and seeds are the major source of nutritional and antioxidant properties. The leaves are enriched with minerals such as calcium, potassium, zinc, magnesium, iron, and copper (Kasolo et al. 2010). Vitamins such as Vitamin A, Vitamin B like folic acid, pyridoxine, and nicotinic acid, vitamins C, D, and E also occur (Mbikay 2012). The minerals are directly involved in human growth and development. Calcium is counted as a significant mineral for body growth. The substitution of iron tablets with *Moringa* powder is used to treat anemia patients (Fuglie 2005). Zinc is important for the appropriate development of sperm cells and it is involved in the synthesis of genetic materials such as DNA and RNA.

The phytochemicals like sterols, terpenoids, tannins, saponins, alkaloids tannins, flavonoids, anthraquinones, and alkaloids have been reported (Berkovich et al. 2013). The leaves also have a low calorific value and are used against obesity. The pods have fibrous properties and are used for digestive problems and to thwart colon cancer (Owusu et al. 2008). It has been shown that the young pods comprise

**Table 13.1** List of nutrients of *Moringa oleifera* in 100gm/plant materials (Gopalakrishnan et al. 2016)

| Nutrients | Fresh leaves | Dry leaves | Leaf powder | Seed | Pods |
|---|---|---|---|---|---|
| Calories (cal) | 92 | 329 | 205 | – | 26 |
| Protein (g)<br>Fat (g)<br>Carbohydrate (g)<br>Fiber (g)<br>Vitamin B1 (mg) | 6.7<br>1.7<br>12.5 0.9<br>0.06 | 29.4 5.2<br>41.2 12.5<br>2.02 | 27.1 2.3<br>38.2 19.2<br>2.64 | 35.97 ± 0.19<br>38.67 ± 0.03<br>8.67 ± 0.12<br>2.87 ± 0.03 | 2.5 0.1 3.7<br>4.8<br>0.05 |
| Vitamin B2 (mg) | 0.05 | 21.3 | 20.5 | 0.06 | 0.07 |
| Vitamin B3 (mg) | 0.8 | 7.6 | 8.2 | 0.2 | 0.2 |
| Vitamin C (mg)<br>Vitamin E (mg)<br>Calcium (mg) | 220<br>448<br>440 | 15.8<br>10.8<br>2185 | 17.3<br>113<br>2003 | 4.5 ± 0.17<br>751.67 ± 4.41<br>45 | 120<br>–<br>30 |
| Magnesium (mg)<br>Phosphorus (mg) | 42<br>70 | 448<br>252 | 368<br>204 | 635 ± 8.66<br>75 | 24<br>110 |
| Potassium (mg) | 259 | 1236 | 1324 | – | 259 |
| Copper (mg)<br>Iron (mg) | 0.07<br>0.85 | 0.49<br>25.6 | 0.57<br>28.2 | 5.20 ± 0.15<br>– | 3.1<br>5.3 |
| Sulphur (mg) | – | – | 870 | 0.05 | 137 |

approximately 7% fiber and about 21% protein. The concentration of amino acid is 30% in pods, 45% in leaves, and 32% in flower. The quantity of linolenic, linoleic, oleic, and palmitic acids is similar in young pods, leaves, and flowers (Sánchez-Machado et al. 2010). A nutrients list of *Moringa oleifera* is shown in Table 13.1.

These groups of essential polyunsaturated fatty acids (PUFAs) have the capacity to regulate the cholesterol. Various investigations represented that *Moringa* seed oil contains around 75% PUFA, setting itself as a substitute for olive oil (Lalas and Tsaknis 2002). One of the research studies reported that seasonal periods influence the nutrient content (Fuglie 2005). Vitamin A was established with more quantity in hot wet period but vitamin C and iron were traced high in cold-dry period (Devarai 2005).

### 13.1.5 Production and Distribution of *Moringa Oleifera*

*Moringa oleifera* native land is marked from the Himalaya Mountains in North India and South Asia. It has been used widely and is termed as a "miracle tree." *Moringa* is cultivated in different parts of the world and the various parts of the tree such as leaves, roots, flowers, and fruit/seed are used for food (Wu and Raven 2001). *Moringa oleifera* cultivation is widely noted in the tropical and sub-tropical region of Africa and the southeastern part of Asia such as Philippines, Sri Lanka, Malaysia, Indonesia, and Taiwan (Al-Zahrani and Ibrahim 2018; Gandji et al. 2018; Owusu et al. 2008). It is also widely adopted in sub-Saharan Africa including South Africa, Benin, Zimbabwe, Madagascar, Burkina, Faso, Tanzania, Cameroon, Chad, Zanzibar, Gambia, Guinea, Kenya, Liberia, Nigeria, Mali, Mauritania, Ghana, Sudan, Ethiopia, Somalia, Zaire, Togo, Uganda, and Senegal. South Asia and India are leading producers of *Moringa oleifera* with 1–three million tons annually of fruits. Commercially *Moringa* has been expanded in the Hawaii, Cambodia, Mexico, and Caribbean Islands. *Moringa oleifera* has been considered as a versatile tree (Lin et al. 2018).

## 13.2 Antioxidant Properties of *Moringa oleifera*

*Moringa oleifera* has been stated to play a potential role for healthy characteristics, attributed to various bioactive constituents such as vitamins, phenolic compounds which are available in significant amounts in many constituents of plants. Generally, "antioxidants" is the term referred for any biomolecules/chemical agents that prevent the consumption of molecular oxygen species. Antioxidants complete the mechanism by a different way to counter free radicals. The first is hydrogen atom transfer (HAT) and the second is single electron transfer (SET) or a combination of both mechanisms.

Naturally occurring antioxidants, especially polyphenols, have the main role in chelating the free radicals and are capable of reducing the oxidative impairment in the tissue through indirect augmentation of cells. The *Moringa oleifera* leaves have been mostly reported to demonstrate the antioxidant properties due to high amounts of polyphenols. *Moringa* dried leaves are a great source of polyphenol compounds like flavonoids, phenolic acids, tannins, saponins, terpenoids, and glycosides.

**Flavonoids** The leaves are the major foundation of flavonoids which are accountable for the antimicrobial activity with the presence of benzo-y-pyrone rings as known structure (Kumar and Pandey 2013). It is shown to be a protective agent in chronic disease with the association of oxidative stress followed by cardiovascular disease and cancer. The main flavonoids in leaves are quercetin, myrecytin, and kaempferol with concentrations of 6, 0.20, and 7.5 mg/g, respectively (Sultana and Anwar 2008). Quercetin is known as strong free radicals chelating agent with multiple therapeutic properties. It is found in dried leaves at a concentration of 100 mg/100 g in quercetin-3-O-β-d-glucoside (isoquercetin or isotrifolin) format (Lako et al. 2007; Atawodi et al. 2010; Bischoff 2008).

**Alkaloids** Glucosinolate and isothiocyanates alkaloids are major compounds that contain the basic nitrogen atoms. In the *Moringa oleifera*, dried leaves have been reported to have several derivative composites including phenylacetonitrile pyrrolemarumine, N, a-L-rhamnopyranosyl lincosamide, 40-hydroxyphenyl ethanamide-α-L-rhamnopyranoside, and glucopyranosyl (Panda et al. 2013; Sahakitpichan et al. 2011). The Secondary metabolites are glucosinolates in the plant (Förster et al. 2015). Glucosinolate and isothiocyanates have been reported to have significant health endorsing characteristics (Dinkova-Kostova, medicine, and 2012).

**Tannins** This phenolic component is water-soluble, which are precipitated gelatin, alkaloids, and other protein compounds. The leaves have been reported with a concentration of 13.0–20.6 g tannin/kg (Teixeira et al. 2014; Richter et al. 2003). Tannins are involved in anticancer, antiatherosclerotic, anti-inflammatory, and hepatoprotective properties (Adebayo et al. 2017).

**Saponins** *Moringa* leaves are a well-known source of saponins which are comprised of isoprenoid-derived aglycone, and it is covalently attached with sugar moieties (Augustin et al. 2011). Freeze-dried leaf saponins concentration has been reported based on dry weight that ranges from 64 to 81 g/kg (Makkar and Becker 1996). It is actively involved as anticancer agent (Tian et al. 2013).

## 13.3 Chemicals Constituent of *Moringa Oleifera*

Phytochemicals have been isolated by different analyses from *Moringa oleifera.* The major polyphenols have been identified from *Moringa oleifera* leaves, seeds, and roots.

**Seeds** It contains major polyphenols, 4(alpha-L-rhamanosyloxy) benzyl isothiocyanate, 4(alpha-L-rhamanosyloxy) benzyl glucosinolate Roridin E, 4(−L-rhamanosyloxy) phenylacetonitrile, 4-hydroxyphenylacetonitrile, and 4-hydroxyphenyl-acetamide, beta-sitosterol, 9-Octadecenoic acid, Veridiflorol, niazimicin, niazirin, glycerol-1-(9-octadecanoate), O-ethyl-4-(alpha-L-rhamnosyloxy) benzyl carbamate, 3-O-(6'-O oleoyl-beta-D-glucopyranosyl)-beta-sitosterol and beta-stosterol-3-O-beta-D-glucopyranoside (Fahey 2005).

**Leaves** 4-(alpha-l-rhamnopyranosyloxy) -benzylglucosinolate, 4-[(4'-O-acetylalpha-L-rhamnosyloxy) benzyl isothiocyanate, Niazirin and Niazirinin-nitrile glucosides, quercetin-3-O-glucoside and quercetin-3-O-(6″-melanyl-glucoside), 3-caffepylquinic acid and 5-caffeoylquinic acid, kaempferol-3-O-glucoside and kaempferol-3-O-(6″-malonyl-glucoside), kaempferide3-O-(2"-O-galloylrutinoside) -7-O-alpha-rhamnoside, kaempferide 3-O-(2″, 3″ –diacetylglucoside), benzoic acid 4-O-alpha-rhamnosyl-(1 → 2)-beta-glucoside and benzaldehyde 4-O-beta-glucoside, kaempferol 3-O-[beta-glucosyl-(1 → 2)-[alpha-rhamnosyl-1 → 6)-beta-glucoside-7-Oalpharhamnoside and kaempferol 3-O-[alpha-rhamnosyl-(1 → 2)-[alpha-rhamnosyl-(1 → 4)-betaglucoside-7-O-apha-rhamnoside together with benzoic acid 4-O-beta-glucoside, Ethyl palmitate, 4-Hexadecen-6-yne, 2-hexanone, Palmitic acid ethyl ester, hexadecanoic acid, 2, 6-Dimethyl-1, 7-octadiene-3-ol,Hi-oleic safflower oil, 3-cyclohexyliden-4-ethyl-E2-Dodecenylacetate, safflower oil (Fahey 2005).

**Roots** Deoxy-niazimicine, p-cymene, 4-(alpha-l-rhamnopyranosyloxy)-benzylglucosinolate and glucosinolate, alpha-phellandrene, aurantiamide acetate 4 and 1, 3-dibenzyl urea (Mishra et al. 2011).

## 13.4 Regulatory Mechanism of Compounds in Biological Activity

### 13.4.1 Antioxidant Effects

The presence of high concentration phytochemicals in *Moringa oleifera* leaves acts as medicinal properties. The extracted phenolic compounds are utilized for patients in an inflammatory situation, hypertension, tumor, diabetes, and chronic heart disease (Pari and Kumar 2002; Posmontier 2011). Phenolic compounds are reported as antimicrobial, antioxidants, and antitumor agents (Ayoola et al. 2008; Davinelli et al. 2015). It is known for primary antioxidant, scavenging single or triplet oxygen, or decomposing peroxides (Murillo and Fernandez 2017; Yanishlieva-Maslarova 2001; Zheng and Wang 2001). Aqueous extracted freeze-dried leaves from the different climatic regions have been shown to have 89–92% inhibition of peroxidation of linoleic acid as well as superoxide radicals chelating activity of β-carotene-linoleic acid (Siddhuraju and Becker 2003; Iqbal and Bhanger 2006). The ecological and soil nature also contributes to the antioxidant effects (Iqbal and Bhanger 2006). The combined ingestion of antioxidant has been shown to be more effective on the damage of cells from free radicals. It is due to the synergistic and cascade mechanism of antioxidants extracted from the *Moringa oleifera* leaves (Ferreira et al. 2008; Mishra et al. 2011; Tejas et al. 2012). The alcoholic extracted *Moringa* leaves contain tannins, saponins, flavonoids, terpenoids, and glycoside proven as medical therapeutic agents.

### 13.4.2 Antihyperglycemic Effects

*Moringa oleifera* has been documented in controlling diabetes. Diabetes is categorized into two types: the first is due to lack of polypeptide insulin hormone that maintains the blood glucose metabolism in the cells. The second type of diabetes accompanying insulin resistance, in which β-cells fails to intellect glucose levels and reduces the insulin signaling, as a result, increase the blood glucose levels (Cerf 2013). Several studies have reported that *Moringa oleifera* extract acts as antidiabetes agent in streptozotocin (STZ)-induced diabetes rat (Divi and BellamkondaRamesh 2012; Al-Malki and El Rabey 2015). The acting molecular mechanism of flavonoids of *Moringa oleifera* reduces the ROS species triggered in the pancreatic β-cells through STZ induction (Mbikay 2012). STZ causes ATP dephosphorylation reactions and support xanthine oxidase for the construction of superoxide and ROS species in β-cells (Sowmya and Sachindra 2012). Therefore, high glucose concentration moves to mitochondria and release the ROS. Beta cells have low level of antioxidant enzymes, which induces apoptosis (Kaneto et al. 1999; Prentki and Nolan 2006).

Reduction in insulin secretion leads to hyperglycemia and moves to type 2 diabetes. Quercetin and phenolic have been stated to have scavenging effect on reactive oxygen species (ROS).

### 13.4.3 Anti-inflammatory Effects

Hyperglycemia leads to multiple complications such as atherosclerosis, nephropathy, and retinopathy. In the high blood glucose condition, glucose counters through proteins and creates advanced glycated end products (AGEs). AGEs muddle the RAGE which is articulated in the immune cells. Binding causes the transcript of cytokines such as interleukin-6 (IL-6) and interferons. The cells adhesion molecules are expressed at the same time on the surface of the endothelium of arteries (Aronson and Rayfield 2002).

### 13.4.4 Hypolipidemic Effects

Phenolic compounds and flavonoids of *Moringa oleifera* leaves influence the lipid homeostasis. It has a major role in lipid regulation via interaction of catalytic domain of HMG-CoA reductase, cholesterol esterase, restriction of cholesterol absorption, controlling the bile salts recycle from guts to liver (Siasos et al. 2013; Adisakwattana and Chanathong 2011). The leaves' phenolic compounds and flavonoids inhibit lipase enzyme and cholesterol esterase enzyme which results in the anticipation of hyperlipidemia (Toma et al. 2012). It has also the ability to regulate the lipid profile by reducing cholesterol. The cholesterol levels are regulated in two ways: first, cholesterol biosynthesis through the mevalonate pathway, in which HMG-CoA reductase catalyzes the rate-limiting progression, and second, fascination of dietary cholesterol and bile salt recycling. The *Moringa oleifera* inhibited the catalytic domain of HMG-CoA reductase enzyme, reducing the cholesterol levels and supporting hypolipidemia (D'Souza et al. 2007). Another bioactive compound, β-sisterol, has been documented for lowering cholesterol in blood plasma in high cholesterol-induced rats (Halaby et al. 2013). Saponins are also reported for restriction of cholesterol via the recycling of bile salts to the hepatocyte cells through fecal excretion (Oyedepo et al. 2013).

### 13.4.5 Hepatoprotective Effects

Quercetin from the *Moringa oleifera* leaves extract has been documented to have a hepatoprotective effect (Anwar et al. 2007; Tejas et al. 2012). There are significant effects of quercetin on the expression level of aspartate aminotransferase (AST), alanine aminotransferase (ALT), and alkaline phosphatase (ALP), indicating the protective nature of hepatocyte cells. It is also reported that quercetin lowers lipid profile in rats' liver (Halaby et al. 2013). The leaves extract has been publicized to lower plasma ALT, AST, ALP, and creatinine and improve liver as well as kidney injury induced through synthetic medications (Sharifudin et al. 2013; Ouédraogo et al. 2013). It has shown a similar effect as observed in induced nephropathy rats (Adeyemi and Elebiyo 2014). In the non-alcoholic fatty liver disease (NAFLD) in guinea pigs, it has been shown to lower the hepatocyte accumulated cholesterol and triglycerides with treatment of *Moringa oleifera* leaves extract (Mused Almatrafi et al. 2017). It has been also reported to reduce plasma ASP in guinea pigs.

### 13.4.6 Anticancer Effects

*Moringa oleifera* has been deliberated to have chemotherapeutic nature and has been shown to regulate the progress of various tumor cells (Karim et al. 2016). Moringa leaves have the ability to oxidative DNA damage of cells and organisms especially accompanying cancer and degenerative diseases (Sikder et al. 2013). The numerous bioactive compounds such as 4-(α-L-rhamnosylosy) benzyl isothiocyanate, niazimicin, and β-sitosterol-3-o-β-D-glucopyranoside occurring in *Moringa oleifera* may be accountable for antitumor property (Abdull Razis et al. 2014). The leaves extract has shown to be effective in pancreatic cancer cells by modulating NF-$_{K}$B signaling promoting efficiency of chemotherapy (Berkovich et al. 2013). Antitumor effects have been also demonstrated in breast cancer cells (Adebayo et al. 2017). The impact of compounds was on cytotoxicity as measured by apoptosis (Sadek et al. 2017). Numerous investigations have established the efficacy of *Moringa oleifera* leaves as an inhibiting agent of cancer in rats (Sadek et al. 2017). Some bioactive components of *Moringa oleifera* and defense nature in different lifestyle disease are represented in Table 13.2.

## 13.5 Health Benefit of *Moringa oleifera*

*Moringa oleifera* has been considered as a versatile tree with interesting health benefits. All the parts of the *Moringa* plant can be consumed by humans (Yalew et al. 2019). Numerous reviews reported the antioxidant, anticancer, anti-inflammatory, antihypertensive, diuretic, anthelmintic, hypoglycemic, antiasthmatic, and antiaging potential properties (Zi Khor et al. 2018, Sandeep et al. 2019, Abd El-Hack et al. 2018, (Swatią et al. 2018). Its benefits of nutritional value occur in higher standards in dietary intake than recommended by the World Health Organization (Lin et al. 2018). In ancient India, *Moringa oleifera* was used for different traditional medical purposes. It was recorded that emperors ate leaves and fruits for possessing healthy skin and sharp brain, and warriors ate leaves extract to become more energetic and release tension as well as pain during the war (Manzoor et al. 2007). *Moringa* plant is considered as nutraceutical food based on the specific chemical compositions (Sánchez-Machado et al. 2010). *Moringa* parts such as leaves, seeds, barks, roots, seed husks, oil, and flower need to be discussed for health treatment.

**Table 13.2** List of bioactive compounds and health benefits from *Moringa oleifera* (Vergara-Jimenez et al. 2017)

| Compounds | Regulatory function | Studies model | Disease |
|---|---|---|---|
| Flavonoids: quercetin | ↓Hypolipidemic and antidiabetic properties lower hyperlipidemia expression of DGAT | Zucker rat<br>Rabbits<br>Guinea pigs | Diabetes<br>Atherosclerosis<br>NAFLD |
| | Inhibition of cholesterol esterase and α glucosidase | In vitro model | Cardiovascular and diabetes |
| | Inhibits activation of NF-kB | High-fat-induced mice | Cardiovascular |
| Chlorogenic acid | ↓glucose and cholesterol in plasma and liver<br>↓ CD68, SERBP1c expression | Diabetic rats<br>Zucker rat<br>Guinea pigs | Diabetes<br>Cardiovascular disease<br>NAFLD |
| | ↓obesity risk | High-fat-induced obesity rats | Obesity |
| | Inhibit enzymes linked to type-2 diabetes | | Diabetes |
| Alkaloids | ↓cardiovascular risk | Cardio toxic-induced rats | Cardiovascular disease |
| Tannins | Anti-inflammatory effect | Rats | Cardiovascular/cancer |
| Isothiocyanates | ↓ expression of inflammatory markers reduction in insulin resistance | RAW macrophages mice | Cardiovascular disease, diabetes |
| | Inhibition of NF-kB signaling | Cell line model | Cancer |
| B-Sitosterol | ↓cholesterol absorption | High-fat-induced rats | Cardiovascular |

### 13.5.1 Leaves

The *Moringa* leaves are considered a rich source of minerals, vitamins, and phenolic compounds like quercetin and kaempferol (Uphadek et al. 2018). It is exhibited to have strong antioxidant properties. The phenolic compound extracted from the leaves acts as a depressant on the central nervous system in a dose-dependent manner via positive regulation of GABA. It is also used traditionally in the treatment of epilepsy and as sedative-hypnotic (Bakre et al. 2013). The leaves have proven as a strong agent for antioxidants and therefore are consumed as diet supplement that could be a useful source to protect from the oxidative stress-induced disease in animals and *Moringa* leaves have also been reported to improve the meat quality for human consumption (Swatią et al. 2018). The leaf extract has been documented as a therapeutic agent to cure cardiovascular disease via restriction of plaque formation in the artery and to lower the nature of lipid in rabbit fed with high cholesterol (Sultana et al. 2018; Ma et al. 2019). The research also suggested that *Moringa* leaf extract promoted axodendritic maturation and neuroprotection (Bezerra et al. 2016). It has been also reported to reduce the negative effects of nephrotoxicity induced by drugs. It has a considerable impact on developing clinical strategies to treat renal failure patient or as adjunct therapy to improve the therapeutic index of nephrotoxic drugs (Ali et al. 2014). Finally, *Moringa oleifera* leaves' extracts contain compounds with wide spectrum antibacterial properties that can prevent the progress of bacteria (Manzoor et al. 2007).

### 13.5.2 Root

*Moringa* root bark extract can cure gastric ulcers and gastric mucosal lesions. It is decreasing acidity and increasing the gastric juice pH. These findings indicate the potential of the antiulcer and antisecretory activity of *Moringa* root bark extracts which could make it future antiulcer drug. (Sánchez-Machado et al. 2010). The root extract having the potency of antimutagenic and antioxidant against sodium azide in TA100 tester strains of *Salmonella typhimurium* and their inhibition of lipid peroxidation were studied, indicating that root extracted in aqueous solution possessed antimutagenic and chelating properties (Pandey et al. 2011). The researchers stated that root extract is capable of reducing and preventing the progress of urinary stones, which displayed its antiurolithiasis properties (Karadi et al. 2006).

### 13.5.3 Seed

Numerous studies have been proven to use *Moringa oleifera* seeds with potential against health problems. The mature seeds are rich in oil with approximately 22–40% crude fat. The analysis of oil compositions marks that it has a high proportion of monounsaturated fatty acids, particularly oleic acid. It contains oleic acids. The higher dietary intake of oleic acid is associated with reducing cardiovascular disease (Ghazali and Mohammed 2011; Flora and Pachauri 2011). Seeds comprise a range of phytochemicals, including β-carotene, α- and γ- tocopherol, Vitamin C, and Vitamin A, having strong antioxidant capacity. The seed extract has been used in many pharmaceuticals and for commercial utilization for its antidiabetes, antiasthmatic, antiarthritic, and hepatoprotective properties. It is also reported for the antibacterial activity of seed extract. The seed extract polyphenols have showed effective antioxidant activity and inhibtion against the Epstein–Barr virus (Singh et al. 2013; Guevara et al. 1999). The seed extract could be used to prevent some of the diseases by controlling the vector, like malaria vector and mosquito vector (Prabhu et al. 2011).

### 13.5.4 Pod Husks

*Moringa* pod husks occur as alkaloids, tannins, flavonoids, triterpenoids, diterpenoids, and cardiac glycosides. It has been shown to have post-antibiotic effects against some Gram-negative and positive bacteria, marking better potency which might need a long dosing regimen. The investigation has shown resistance to one or more conventional antibiotics. Such an organism including the multidrug-resistant to active phytochemicals of pod husks could indicate a substitution perspective, which may serve as a medication for antimicrobial (Singh et al. 2013). The husks also demonstrate an underlying mechanism of anti-inflammation. Some pod husks compound shed hypertensive activity (Faizi et al. 1998; Muangnoi et al. 2012).

The above explanation shows that *Moringa oleifera* parts present lots of health benefits including coronary heart disease, antidiabetes, antinephrotoxicity, antibacterial, antimutagenic, antiulcer, anticancer, antiurolithiatic, antihypertensive, and anti-inflammation potential. They represent the good health benefits of *Moringa oleifera* for each part and clarifying the surname of “Miracle tree.”

## 13.6 Conclusion

*Moringa oleifera* is proved in various cases to regulate the therapeutic and nutritional properties. *Moringa oleifera* leaves’ extract is widely studied for bioactive phytochemicals and well documented, which is gaining importance in research regarding the therapeutics nature for antioxidant, antitumor, anti-inflammation, antidiabetes, antihyperlipidemia, and antimicrobial properties. The accountability of the therapeutic possessions of *Moringa oleifera* may lead to an illustration of the molecular mechanism and development of therapeutics drugs. An extensive research on humans, including clinical trials, are needed to be conformed of chronic effects.

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# Mushroom

# 14

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**Abstract**

Mushrooms have been consumed over years as a part of human diet. Due to the therapeutic value of mushroom, it is categorized as a functional food with the property of disease prevention in humans. The presence of biologically active compounds having different medicinal properties provides an opportunity to develop edible mushrooms into functional foods with enhanced nutritional value and numerous health benefits. Mushrooms have cardiovascular, antidiabetic, and immune-modulating properties in order to prevent the risk of cancer and control blood sugar level with substantive antioxidant activity, which are recorded in both wild as well as cultivated species. Various bioactive compounds in mushrooms like phenolics and alkaloid and organic acid contents have the ability to inhibit lipooxidase enzymes, scavenge free radicals, and capture metals and thus contribute to the antioxidant property of mushrooms. Due to the antioxidant properties of the phenolic compounds which are present in mushrooms, there is ample scope for the provision of a lot of health benefits. Flavonoids constitute the major proportion of phenolic compounds present in mushrooms. The bioactive compounds of mushrooms which are responsible for producing various therapeutic effects are commonly obtained from their fruiting bodies. The content and concentration of these bioactives depends upon the cultivation technique, extraction method, and the type of bioactive component.

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**Keywords**

Mushrooms · Bioactive components · Antioxidant property · Health benefits

## 14.1 Introduction

Botanical name: *Agaricus bisporus.*

Common name: Mushroom.

Mushroom (*Agaricus bisporus)* is the fleshy spore-bearing body of a fungus, which is generally produced on the soil or its food source. It typically refers to the fruit bodies of members belonging to the order *Agaricales*, whose type genus is *Agaricus*. However, the extended definition of the term "mushroom" can also refer to either the entire fungus when in culture, the thallus (called a mycelium) of species forming the fruiting bodies called mushrooms, or the species itself.

Mushrooms are consumed as a part of diet across the world due to their potential nutritional properties. There is a wide range of compounds which are obtained from mushrooms, with their distinct properties providing different health benefits. This makes mushrooms an interesting field of study and a very useful source of bioactives for the prevention of various diseases (Gao et al. 2004; Mattila et al. 2002). Mushrooms have been consumed since ancient times across different cultures around the world. They are broadly classified into three groups, i.e., edible mushrooms, medicinal mushrooms, and poisonous mushrooms. In case of edible mushrooms, the fruiting body is consumed as such or in any other dried form, e.g., *Agaricus bisporus, Pleurotus ostreatus*, etc. Medicinal mushrooms such as *G. lucidum* are not essentially used directly as diet due to their undesirable organoleptic characteristics, but are consumed in the form of extracts or concentrates. Poisonous mushrooms are inedible due to the presence of certain poisonous substances in them, e.g., *Amanita phalloides* (Cheung 2010).The common mushroom cultivated worldwide is *Agaricus bisporus* followed by *Pleurotus ostreatus* and *Flammulina velutipes.*

Various studies have been carried out to explore the use of mushrooms for nutritional as well as therapeutic purposes. The different proposed effects on health include antitumor, immunomodulating, antioxidant, radical scavenging, cardiovascular, antihypercholesterolemia, antiviral, antibacterial, detoxification, hepatoprotective, and antidiabetic effects (Wasser 2010). The fundamental approach to study the different health benefits of mushrooms on the human body involves the isolation, characterization, and administration of pure bioactive compounds from the extracts of mushrooms. The different bioactives can also produce a synergic effect, thereby providing promising therapeutic effects. The use of different bioactives in combination has been shown to produce better health effects due to their concerted effect (Borchers et al. 2004; Vickers 2002).

The bioactive compounds of mushrooms which are responsible for producing various therapeutic effects are commonly obtained from their fruiting bodies. The content and concentration of these bioactives depends upon the cultivation technique, extraction method, and the type of bioactive component (Barros et al. 2007b; Mattila et al. 2001). The different bioactive compounds present in the mushrooms include polysaccharides, glycoproteins, proteins, lipids, and secondary metabolites (Lull et al. 2005).

Polysaccharides are the most potential bioactives present in mushrooms, which are usually the components of the cell wall, such as β-glucans, trehalose, chitin, etc. (Sánchez 2017). They have been demonstrated to provide health benefits such as anticancer, antioxidant characteristics, neuroprotection, and immunomodulation (Valverde et al. 2015). The bioactive proteins are essential functional components of mushrooms which possess ample applications in the development of pharmaceutical components. These include lectins, immunomodulatory proteins, ribonucleases, ribosome-inactivating enzymes, etc. (Xu et al. 2011). These proteins have a wide range of biological activities by possessing antitumor characteristics and immunomodulatory activities (Zhang et al. 2010). Mushrooms are generally low in their fat content, mostly dominated by unsaturated fatty acids such as palmitic acid, oleic acid, and linoleic acid (Carneiro et al. 2013). The secondary metabolites present in mushrooms include phenolic compounds, organic acids, terpenes, steroids, terpenoids, alkaloids, lactones, and vitamins, which offer a lot of health benefits (Sánchez 2017). The different terpenes found in mushrooms are shown to possess an inhibitory effect on cholesterol synthesis (Komoda et al. 1989) and angiotensin-converting enzymes (Morigiwa et al. 1986). The phenolic compounds in mushrooms provide a lot of health benefits by possessing antioxidant properties. They produce anti-inflammatory, antimicrobial, antithrombotic, cardioprotective, and vasodilator effects (Ferreira et al. 2009; Heleno et al. 2012).

### 14.1.1 History

Mushrooms have been used in the world since time immemorial not only because of their aromatic and nutritional properties but also for their medicinal values. Presently, they are well known for culinary properties due to the presence of high-quality proteins, vitamins, fibers, and other medicinal properties due to which they are called nutraceutical (Benzie and Strain 1996). The consumption of mushrooms and their medical application are deep rooted in Asian countries and their modern societies. However, they have been neglected for centuries in many European countries. The cultivation of mushrooms started with artificial inoculation of twigs with Auricularia auricular- judae in China 600 years AD. Also, Shiitake in China was first cultivated on logs around 1000 to 1100 AD (Lull et al. 2005). In Europe, around 300 years ago, mushroom cultivation came up in Paris, when gardeners first grew button mushrooms (*Agaricus bisporus*) on beds fertilized with dung (Zhishen et al. 1999). In different countries for different people, the word “mushroom” means different things. Mushrooms, called as the “Food of Gods,” have been liked by humans since ancient times. They provided strength for warriors in battles. Traditionally, mushrooms were harvested wild and were difficult to domesticate and cultivate (Mattila et al. 2002). Collection of edible mushrooms from wild lands is still common in southern Asia and developing countries. The cultivation of some species of mushrooms has a long history; they were grown on a small scale and only in particular areas and seasons. The consumption of mushrooms in the early days of civilization was due to their palatability and unique flavor. The consumption of mushrooms in the early days has been reviewed by various workers (Buller 1915; Rolfe and Rolfe 1925). The current use of mushrooms is different from traditional use as research on chemical composition has been done to a great extent, which showed that mushrooms can be utilized as a diet to battle various diseases in humans.

### 14.1.2 Production in India and the World

Mushroom production is increasing very fast throughout the world due to the greater awareness of its nutritional and medicinal value. Besides its unique flavor and texture, the consumption of this fancied item is also a natural corollary to the economic development of a country (Carneiro et al. 2013). The production of mushrooms in the world is estimated at about 12 million tons with more than an 8% annual growth rate. However, India, being a late starter, is rapidly catching up; the present production is at the lakh ton mark and the annual growth is still above 15% (Cheung et al. 2003). Currently, the highest production of mushrooms is from Punjab followed by Haryana and Maharashtra. The task is not confined to the seasonal growing in the northern area but it has spread widely in the country. Apart from seasonal farmers, various large environmentally controlled units have emerged as export-oriented units. The country has the largest mushroom unit of the world, which produces 200 tons of button mushrooms per day and its export estimate is about 25% of the US imports (Jeong et al. 2010). The production of edible mushrooms in the world has increased more than 30-fold from 1978 (1 billion kg) to 2013 (34 billion kg). This is a remarkable achievement considering the population of the world has increased only 1.7-fold from 1978 (4.2 billion) to 2013 (7.1 billion). Therefore, the mushroom per capita consumption has increased at a faster rate, mainly from 1997, which now exceeds 4.7 kg annually. In 2013, almost all consumption of mushrooms in China, the European Union, and India was supplied from domestic sources and consumption in the US, Japan, Canada, and Australia was supplied mainly by domestic sources but by significant amounts of imports. China is the largest producer of mushrooms. More than 30 billion kg of edible mushrooms were produced in China in 2013, which accounts for about 87% of the total production. The production of mushroom increases continuously, with China being the largest producer in the world. However, wild mushrooms have been found to be more important for their nutritional and sensory characteristics (Moro et al. 2012).

### 14.1.3 Botanical Description of Mushrooms

Mushrooms are a diversified group of macro fungi belonging to Ascomycetes and Basidiomycetes with a cell cycle including the formation of sexual spores (Wang et al. 2013). The spores are located in a special structure called the ascus (Ascomycetes) or the basidium (Basidiomycetes).

These mushrooms grow below the soil surface at a depth of 10–20 cm (hypogenous macro fungi or truffles) or grow above the soil surface (epigeous macro fungi) in an umbrella-like structure, which include basidiospores (Zhang et al. 2015). The former of these belong to ascomycetes and grow with a host plant as ectomycorrhizal mushrooms (EMM) in a symbiotic relationship. The members bear thin, bladelike gills on the undersurface of the cap from which spores are shed. The sporophore consists of a pileus and a stalk. The sporophore emerges out from an underground network of threadlike strands called as mycelium. The fruiting bodies of mushrooms occur in rings called fairy rings. The falling of spores in a favorable spot leads to the formation of mycelium and producing hyphae that grows in all directions, forming a circular mat of hyphal threads. Fruiting bodies, produced at the edge of this circular mat, may widen the ring for hundreds of years (Kozarski et al. 2015a, 2015b).

Edible mushrooms have been divided into five categories according to the derivation of their names, viz., those named according to the taste, morphology, growth habit, texture, and habitat (Oso 1975). Examples in each category are taste *(Volvariella volvacea, Volvariella esculenta)Termitomyces clypeatus*; morphology (*Termitomyces manniformis*) *Termitomyces robustus*, *Schizophyllum commue*, *Agrocyber broadway*; growth habit (*Termitomyces globulus*, *Pleurotus tuber-reguim*); texture *Pleurotus squarrousulus*, *Psathyrella atroumbonata*; habitat *(Francolinus bicalcaratus*). Furthermore, the natives have observed the growth of many fungi on different kinds of dead wood and have named each fungus after the wood on which it grows (Mattila et al. 2002).

## 14.2 Antioxidant Properties of Mushrooms

Mushrooms are nutritionally considered as functional foods that act as an integral part of our diet for years. They are recognized for their potential therapeutic properties, which are effective to treat and prevent varieties of disorders (Lim et al. 2007; Moro et al. 2012; Silveira et al. 2014). The common mushroom species produced in a suitable ecological environment are *Hericium erinaceus* (Lion's head or pompom), *Auricularia auricula-judae* (ear),*Grifola frondosa* (maitake), *Agaricus* spp., *Lentinula edodes* (shiitake), *Pleurotus* spp. (oyster), *Volvariella volvacea* (straw) *Ganoderma lucidum* (lingzhi), *Flammulina velutipes*, *Tremella fuciformis*, *Pholiota nameko*, *Lepista nuda* (blewit), and *Coprinus comatus*(shaggy mane). Those of highest financial value are usually fashioned under artificial circumstances, i.e., on a well distinct substrate and under full climatization. These are mostly *Agaricus bisporus* (button mushroom) *Flammulina velutipes, Lentinula edodes*, *Pleurotus s*pp. Mushroom manufacturing is increasing continuously, with China being the biggest manufacturer around the world. Fruiting bodies of fungi (mushrooms) are valued for their chemical and nutritional properties apart from their texture and flavor. Mushrooms belonging to different taxa having diverse ecological niches show various degrees of antioxidant potentials. Insufficient nutrition due to current lifestyle and raise of average stability are the two main reasons for the growing incidence of disease all over the world. Imbalanced metabolism and an excess of reactive oxygen species (ROS) causing oxidative stress result in various disorders such as heart disease, metabolic disease, severe neural disorders such as Parkinson's and Alzheimer's, some cancers, and premature aging. However, wild edible mushrooms have high carbohydrate, protein, water, fiber content, rich source of trace elements, and low in fat/energy levels, thus making them an admirable source for making low caloric foods. Some species of edible mushroom species are highly nutritious and may evaluate satisfactorily with eggs, milk, and meat. Amino acid compositions of mushrooms are equivalent to animal proteins, which is predominantly imperative considering the cost of those proteins and the occurrence of diseases caused due to animal meat. These natural products act as a good resource for the development of therapeutic compounds with anti-inflammatory properties without any toxic effects (Yuan et al. 2006). Some bioactive compounds has been isolated from plants (Wang et al. 2013), rhizomes (Debnath et al. 2013), and marine algae (Kim et al. 2014) for their anti-inflammatory effects, studied by various mechanisms. Mushrooms (fruiting bodies, mycelia, or their submerged fermentation broth) are a rich source of bioactive compounds whether wild, edible, or cultivated species (Alves et al. 2013) and these bioactive metabolites comprise of phenolic compounds, polysaccharides, terpenoids, lectins, glycoproteins steroids, and several lipid components (Reis et al. 2012). Anti-inflammatory properties are related with a fall in the production of nitric oxide (NO) and other inflammatory mediators such as tumor necrosis factor (TNF-a), interleukins (IL 1b, IL-6, IL-8), and prostaglandin E2 (PGE2), which results in the reduction of inflammation (Choi et al. 2014). Mushrooms have cardiovascular, antidiabetic, and immune-modulating properties in order to prevent the risk of cancer and controlling blood sugar level with substantive antioxidant activity, which are recorded in both wild and cultivated species. Various bioactive compounds in mushrooms such as phenolics, alkaloids, and organic acid contents contribute to the antioxidant activity and free radical scavenging properties with their ability to inhibit lipooxidase scavenge free radicals and capture metals. Wild varieties of mushrooms are consumed by local and tribal communities and impact the health and nutrition as they contain significant amounts of flavonoids, protein, lycopene, β-carotene, etc., which are usually missing in a poor man's diet. The main bioactive compound found in mushroom is polysaccharide, which has an important antitumor role. Extraction of bioactive compounds mainly polysaccharides from Pleurotusostreatus reported high antitumor activity against the HeL tumor cell line (Tong et al. 2009). Crude polysaccharides from fruit bodies of Lentinus polychrous species of mushrooms have been reported to have about 45% of cytotoxicity against the human breast adenocarcinoma cell (Thetsrimuang et al. 2011). In recent times, it was discovered that methanol and/or water extracts from edible mushrooms contain important antioxidant activities (Mau et al. 2005; Ferreira et al. 2007; Ramırez-Anguiano et al. 2007; Gursoy et al. 2009; Vaz et al. 2011). Further investigation revealed that phenols contain the main antioxidant activity present in crude extracts of mushrooms (Barros et al. 2007a; Mau et al. 2005; Ramırez-Anguiano et al. 2007). Mushrooms containing phenolic compounds exhibit a wide range of biological effects such as anti-inflammatory, antibacterial, antiallergic, antithrombotic, hepatoprotective, anticarcinogenic, antiviral, and vasodilatory actions; these biological functions have been accredited to their antioxidant activity and free radical scavenging. Flavonoids are an extensively distributed group of plant phenolic and have been reported to be highly effective scavengers for most types of oxidizing molecules. However, singlet oxygen and various free radicals are possibly involved in tumor promotion and DNA damage. Various health benefits of tocopherol as a bioactive compound are well renowned. R-Tocopherol is the primary form of vitamin E; it is a lipid-soluble antioxidant, functions as a chain breaking antioxidant for lipid peroxidation (LP) in cell membranes, and also acts as a scavenger of ROS such as singlet oxygen. It acts as the first line of defense against LP; it also protects polyunsaturated fatty acids (PUFAs) in cell membranes from free radical attack through its scavenging activity in biomembranes at early stages of LP. The antioxidant properties of carotenoids exhibit various health benefits; it is inversely related with cancer risk in epidemiologic studies and promising results are reported in laboratory assays. Lycopene helps in the prevention of chronic diseases, which has been reported in epidemiological studies as well as in tissue culture experiments by using human cancer cell lines, human clinical trials, and animal studies. Oxidation is very necessary for every living organism for fabrication of energy to carry out various biological processes. However, on the other hand, the uncontrolled production of oxygen results in formation of free radicals, which form the bases of many diseases such as rheumatoid arthritis, cancer, and atherosclerosis as well as in degenerative processes linked with aging (Turkoglu et al. 2006). Organisms are protected against free radical damage by various enzymes such as catalase and superoxide dismutase or compounds such as tocopherols, ascorbic acid, and glutathione (Mau et al. 2002). Reactive oxygen species are not generated internally only in an organism, but is also caused through various external sources such as ionizing radiation, ultraviolet light chemotherapeutics, environmental toxins, and inflammatory cytokines. Inhalation of various toxic chemicals from the environment has become inevitable in modern civilization. Dietary intake is another very imperative source of antioxidants and may add to oxidative homeostasis apart from endogenous antioxidant defense mechanisms of an organism. Antioxidant-containing foods and antioxidant supplements may be used to protect food quality and reduce oxidative damage by preventing oxidative deterioration. In food packing and production, antioxidants are expansively used in anti-aging, health care, and cosmetics. The growing penchant for cosmetics and healthy food, health and wellness foodstuff is influencing the growth of the antioxidant markets. With increasing demand for cosmetics and nutrition, products obtained from natural sources are also pouring into the natural antioxidant market. Population growth and the rising healthcare spending levels have led to a reliable increase in the demand for antioxidant products. The antioxidant market by product type is categorized into natural antioxidants and synthetic antioxidants. Natural antioxidants are segmented into fungal extracts and plant spices (marjoram, oregano, sage, rosemary, thyme, clove, cinnamon, basil, pepper, and nutmeg), glutathione, zinc (Zn), selenium (Se), flavonoids, ubiquinol (fully reduced form of coenzyme Q10), vitamin A (including carotenoids), vitamin E (including tocopherols and tocotrienols), and vitamin C. Synthetic phenolic antioxidants comprise of butylated hydroxytoluene (BHT) butylated hydroxyanisole (BHA), and others, e.g., *tert*-butylhydroquinone (TBHQ), propyl gallate, and ethoxyquin (EQ), which all successfully inhibit oxidation. Synthetic antioxidants, as compared to the natural ones may lead to the production of toxic substances under certain circumstances. However, BHA, which is very often used as an additive in food commerce, can have negative effects on the guideline of the activity of nitrogen-activated protein kinase (MAPK), depending on the dosage. Various synthetic antioxidants are certified for use as feed additives in the European Union. According to Bhattacharyya et al. 2014, various factors are responsible for the generation of reactive oxygen species.

The nutritive value of mushrooms has suddenly become known and documented not only by mushroom farmers and researchers but also by the general consumers. Moreover, along with their good flavor, mushrooms have constructive chemical composition with high amounts of functional low total fat level, proteins, and a high proportion of polyunsaturated fatty acids (PUFAs), which helps to make low-calorie diets. Edible mushrooms provide a nutritionally significant content of vitamins ($B_1$, $B_2$, $B_{12}$, C, D, and E). Mushrooms have high contents of mannitol and low glycemic index, which is especially beneficial for diabetics. Mushrooms have very low content of sodium (Na) concentration, which is valuable for hypertensive patients and a high concentration of phosphorus (P) and potassium (K), which is an imperative orthomolecular feature. In Asian countries, mushrooms are used as a vital source of home remedies against various diseases caused due to oxidative stress. There is no significant difference between medicinal mushrooms and edible mushrooms because many of the edible species have therapeutic properties. Apart from antioxidant properties, mushrooms have received substantial consideration for their biological activities, such as antidiabetic, hypolipidemic, hepatoprotective, immune-stimulant antitumor, antiviral, anticomplementary, anticoagulant, and immunological activities, which made them suitable for use in cosmetics, agriculture, food, biomedicine, and wastewater environmental management. Numerous varieties of edible wild mushroom species, growing in various ecological surroundings, are known.

### 14.2.1 Polyphenols Including Flavonoids

Polyphenols comprise of most copious group of antioxidants in the diet. Various effects of dietary polyphenols on human health have developed considerably in the past 20 years. One of the major difficulties of elucidating the health effects of polyphenols is the huge amount of phenolic compounds present in food comprising of different biological properties. These components may be categorized into different groups on the basis of their phenolic rings and the structural elements which bind these rings to each other. Thus, a difference is made between the stilbenes, phenolic acids, flavonoids, and lignans. Most of the polyphenols present in food are in the form of polymers esters or glycosides. These substances are not able to absorb in their native form, so they must be hydrolyzed by the colonic microflora before absorption or intestinal enzymes. During absorption, polyphenols are conjugated and this system mostly includes glucuronidation methylation and sulfation conjugated derivatives of polyphenols are expansively bound to albumin. However, no conjugated metabolites are usually present in the blood or may be present in low concentrations. Major differences in bioavailability of polyphenols are now well-established facts and the influence of structural factors is better understood.

### 14.2.2 Regulation of Antioxidant Systems

Due to oxidative stress, an organism develops responses in order to prevent or neutralize negative ROS effects. These responses are mainly based on up-regulation of enzymes and antioxidants. Their mechanisms include transduction of signals through specific pathways' ROS sensing and up-regulation of target genes in order to boost the level of their products. Humans comprise of a complicated system of adaptive responses to ROS exposure, having several components. Due to low-intensity oxidative stress, the Kelch-like ECH-associated protein 1/NF-E2-related factor 2 (Keap1/Nrf2) system up-regulates genes encoding antioxidant enzymes. It is acknowledged to be activated by minute amounts of ROS. Transitional intensity oxidative stress up-regulates antioxidant enzymes and induces soreness proteins and heat shock proteins via the MAPK heat shock factor and NF-κB, activator protein-1 *(*AP1), (heat shock transcription factor, HSF). Due to high intensity oxidative stress, perturbations in mitochondrial permeability transition pores (MPTP) may take place. The oxidative stress also leads to the destruction of electron transporters and finally activates the apoptosis cascade (Lushchak 2014). Up-regulation of antioxidant systems raises their potential to abolish ROS, creating in this way auto-regulated negative feedback control loops.

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

The antioxidant activity of mushrooms is due to the presence of bioactive components found in both cultivated as well as wild varieties. The antioxidant activity of some members of *Agaricus* species is found to be higher than gallic acid and ascorbic acid. The type of bioactive component present in mushrooms depends on factors such as species, stage of development, and habitat (Pinto et al. 2013). These components can act as free radical scavengers at different stages of oxidation process as well as provide various health benefits to humans such as

**Table 14.1** Bioactive compounds present in mushrooms

| Bioactive component | Subclasses | Examples present in mushrooms | References |
|---|---|---|---|
| Phenolic compounds | Phenolic acids | *Hydroxybenzoic acids* such as p-hydroxyl benzoic acid, gallic acid, gentisic acid, homogentisic acid, syringic acid, vanillic acid, veratric acid, protocatechuic acid, and vanillic acid.<br>*Hydroxycinnamic acids* such as p-Coumaric acid, o-coumaric acid, caffeic acid, ferulic acid, sinapic acid, and quinic acid. | Ferreira et al. (2009) |
| | Flavonoids | Myricetin, catechin, hesperetin, naringenin, naringin, formometin, biochanin, pyrogallol, resveratrol, quercetin, rutin, kaempferol | |
| Organic acids | | Oxalic acid, malic acid, citric acid, and fumaric acid. | Stojkovi'c et al. (2014) |
| Poly Saccharides | | β glycans | Batbayar et al. (2012) |
| Carotenoids | | B-carotene, lutein, and lycopene | Kozarski et al. (2015a, 2015b) |
| Vitamins | Ascorbic acid (vitamin C) | | |
| | Tocopherols | α, β, γ, and δ tocopherols | Ferreira et al. (2009) |

prevention of heart attack and reduction in glucose and cholesterol levels in blood (Jeong et al. 2010).The bioactive compounds present in mushroom are shown in Table 14.1.

Before the process of characterization of antioxidant compounds in mushroom, steps such as sample preparation and extraction are necessary to be carried out. The steps involved in sample characterization are described below:

**Preparation of the Sample** The fruiting bodies of mushrooms after procurement are cleaned and washed usually by distilled water to remove the residual soil and dirt. The sample is then cut into pieces, dried, and ground before extraction. Drying of the sample can be done by a conventional oven at 40°C for about 12 hours. Nowadays, freeze-drying is carried out for better retention of antioxidant properties of mushrooms. The ground samples are packed in plastic bags or hermatically sealed in airtight containers and stored at freezing temperature before extraction (Gan et al. 2013).

**Extraction** It is considered as the most important step for characterization of antioxidant compounds in any sample. For extraction of antioxidants from mushrooms, 5 grams of the ground sample is taken in a conical flask and mixed with about 200–250 ml of solvent (ethanol, methanol, distilled water, or acetone). The mixture is stirred or agitated between 160 and 200 rpm for 1 hour at ambient temperature. After the agitation period is over, the mixture is centrifuged and then

**Table 14.2** Antioxidant characterization techniques used in the study

| Chemical techniques/assays | Biochemical techniques/assays | Electrochemical techniques/assays |
|---|---|---|
| (i) Measurement of bioactive components<br>(ii) Measurement of DPPH scavenging activity<br>(iii) Measurement of reducing power | (i) Measurement of inhibitory effect on bleaching of β-carotene<br>(ii) Measurement of inhibitory effect on hemolysis of erythrocytes<br>(iii) Measurement of inhibitory effect on peroxidation of lipids | (i) cyclic voltammetry<br>(ii) differential pulse voltammetry |

filtered to remove the residual material from the extract. The extract is concentrated to dryness in a rotary vacuum evaporator at 40°C and reduced pressure to remove the solvent without affecting the antioxidant property of the extract. The dried extract is stored in the dark and then used for analysis (Tibuhwa 2014).

**Characterization** It has been studied that mushrooms are an important source of components with antioxidant activity. Barros et al. (2008) used a simple classification of techniques used for characterization of antioxidant activity of mushrooms. The antioxidant characterization techniques used in the study are shown in Table 14.2.

According to various studies, the most commonly used analytical methods for characterization of antioxidant components in mushroom are discussed below:

**Estimation of Bioactive Components** It involves estimation of total phenols, flavonoids, tocopherols, carotenoids, etc.

### 14.3.1 Total Phenolic Content (TPC)

Total phenolic content in mushrooms is determined according to a method given by Xu and Chang 2007. This method involves spectrophotometric determination of TPC by the Folin–Ciocalteau method using gallic acid as a standard. A standard curve is prepared between absorbance and gallic acid concentration values. Folin–Ciocalteau's Reagent (FCR) is diluted with water (about 10 times). The required quantities of sample extract, FCR (diluted form), and sodium carbonated (known concentration) are added to a test tube. The mixture is allowed to stand for about 2 hours in dark conditions and then the absorbance is taken at 765 nm. TPC values are expressed as mg GAE/gram of extract.

Gan et al. (2013) studied that different solvents show different extraction yields of phenols. It was shown that water resulted in higher extraction of phenols than aqueous ethanol and total phenolic content of Brazilian mushroom was found to be higher than button mushroom. According to a study conducted on few varieties of mushroom, the TPC of these varieties ranged from 5.39 to 9.24 mg GAE/gram of sample extract with minimum values present in *C. cornucopioides* and maximum value present in *C. ventricosum*.

### 14.3.2 Total Flavonoid Content (TFC)

Total flavonoid content of mushrooms is also determined spectrophotometrically using quercetin or catechin as a standard. According to a method given by Jagadish et al. (2009) used for studying the effect of boiling on antioxidant and other preventive properties of *Agaricus bisphorus*, the sample extract is mixed with a known amount of distilled water (deionized) and sodium nitrate solution (known concentration). The mixture is allowed to stand at room temperature for 5 minutes followed by addition of a required quantity of aluminum trichloride solution (known concentration). The mixture is again allowed to stand at room temperature for about 6 minutes followed by addition of a few milliliters of sodium hydroxide solution (1 M). Absorbance of the mixture is recorded at 510 nm. Total flavonoid content values are taken as mg CAE/gram or catechin equivalents per gram of extract from the sample. TFC values of few varieties vary from 1.69 to 3.47 mg/g, with minimum values present in *S. rugoso-annulata* and maximum values present in *L. amethystea*. Various studies revealed that the stage of development of mushrooms also affects the flavonoid content and higher values of TFC are present in those stages of mushrooms in which the spores are not fully developed.

### 14.3.3 Carotenoids

The two main Carotenoids present in mushrooms are Lycopene and β-Carotene. These Carotenoids are determined mainly by a spectrophotometer. Since Carotenoids are fat-soluble pigments, acetone and hexane are mostly used as extraction medium. The extract obtained is filtered through whatman filter paper no.4 and absorbance is recorded at 453, 505, and 663 nm. Lycopene and β-Carotene are estimated using the formulae given below:

$$\text{Lycopene} = -0.0458 \times A_{663} + 0.372 \times A_{505} - 0.0806 \times A_{453}$$

$$\beta - \text{Carotene} = 0.216 \times A_{663} - 0.304 \times A_{505} + 0.452 \times A_{453}$$

The values of Lycopene and β-Carotene are taken in mg/100 ml of extract obtained from the sample. These values are then expressed in μg/gram of extract. Barros et al. (2008) used different methods for determination of antioxidant potential of five varieties of mushroom such as *Agaricus bisporus, Agaricus arvensis, Agaricus romagnesii, Agaricus sivaticus, and Agaricus silvicola*. All the types of mushroom were procured from Portugal. After determination of Carotenoids, it was observed that Lycopene content in these types ranged from 0.38 to 4.70 μg/gram and β-Carotene content varied from 1.32 to 8.52 μg/gram. The order of Lycopene and β-Carotene content in the types of mushrooms taken for evaluation was *Agaricus romagnesii* > *Agaricus bisporus* > *Agaricus silvicola* > *Agaricus sivaticus* > *Agaricus arvensis*.

The individual bioactive components in mushroom can also be identified and then quantified by high-performance liquid chromatography (HPLC). The HPLC system consists of a pump that pumps the sample through a column. The column consists of a stationary and a mobile phase. The system is provided with a detection device used to record the output. The result is obtained in the form of a chromatogram showing different peaks for different components. The system gives the phenolic profile of the sample based on the retention time of the individual components through the column. At a particular wavelength, the retention time of a particular component and absorption is compared with a standard used, which leads to identification and quantification of components present in a sample (Kim et al. 2008).

### 14.3.4 DPPH Radical Scavenging Activity

Diphenyl picryl hydrazyl (DPPH) radical is a free radical used to determine the scavenging activity of antioxidants present in a particular sample. According to a method used by Liu et al. (2012) for determination of antioxidant activity of five different varieties of mushroom procured from china, about $6 \times 10^{-5}$Molar solution of DPPH is prepared in methanol. About 0.1 ml of extract obtained from mushroom is mixed with 3.9 ml of DPPH solution. The mixture after shaking vigorously is allowed to stand for about an hour in dark conditions. Absorbance of the mixture is taken after an hour in a spectrophotometer at 517 nm using DPPH solution without the extract as blank. Lower values of absorbance indicate higher radical scavenging activity. The formula for determination of scavenging activity is:

$$\text{Radical scavenging activity } (\%) = [(A_{DPPH} - A_{SAMPLE})/A_{DPPH}] \times 100$$

$A_{DPPH}$ represents absorbance of DPPH solution without the extract and $A_{SAMPLE}$ represents absorbance of the extract mixed with DPPH solution.

The $EC_{50}$ value represents the extract concentration showing 50% radical scavenging activity. It is obtained from a graph plotted between different extract concentrations and radical scavenging activity. Butylated hydroxyl anisole and ascorbic acid are the most used controls for determination of $EC_{50}$ values.

### 14.3.5 Ferric Reducing Antioxidant Power (FRAP)

For FRAP assay of extract from the mushroom sample, it is necessary to prepare a “FRAP reagent” by combining a required quantity of solutions of TPTZ [2,4,6-Tri (2-pyridyl)-s-Triazine], acetate buffer, and $FeCl_3 \times H_2O$ of known concentrations. The FRAP reagent (1.8 ml) is added to a test tube and heated at 30°C for 10 minutes. After the period of 10 minutes, 100 μl each of the sample extract and distilled water are mixed with FRAP reagent present in the test tube and the mixture is heated for half an hour at nearly ambient temperature (30°C). Absorbance of the FRAP reagent after heating and absorbance of the reagent containing the extract and distilled water after heating is taken at 593 nm (Benzie and Strain 1996). The FRAP value is calculated using the formula:

$$\text{FRAP value} = \text{Absorbance of (FRAP reagent} + \text{Extract)} \\ - \text{Absorbance of (FRAP reagent)}$$

FRAP value obtained in the formula above is determined as $Fe^{2+}$ E (micromoles)/ gram of mushroom extract.

A higher FRAP value represents higher antioxidant activity of the sample. According to a study conducted by Muhammad et al. (2019) on evaluation of antioxidant capacity (both primary and secondary) of a variety of mushrooms obtained from three different parts of Penang island in Malaysia, button mushroom showed the highest reducing activity(84.60%) among all the varieties taken for evaluation and the order of the reducing activity in percentage was:

$$\text{Button mushroom}(84.60\%) > \text{Kukur mushroom } (24.42\%) > \\ \text{Maitake mushroom } (39.46\%) > \text{Oyster mushroom } (24.42\%) > \\ \text{White mushroom } (17.06\%) > \text{Abalone mushroom } (16.35) > \\ \text{Bunapi mushroom } (15.95) > \text{Bunashimeji mushroom } (14.99) > \\ \text{Enoki mushroom } (12.86\%).$$

### 14.3.6 B-Carotene Bleaching Effect

This assay is carried out to check the ability of the extract to prevent β-Carotene from bleaching, which is predominant under conditions favorable for oxidation of plant pigments. Bleaching of β-Carotene is prevented by the presence of antioxidants in the extract. For this, an assay given by Barros et al. (2007c) is used with slight modifications, in which chloroform is used to prepare the solution of β-Carotene. An aliquot of a few milliliters is taken from the solution and is subjected to removal of solvent (chloroform). After removal of chloroform, it is added with linoleic acid, tween 80, and distilled water. Tween 80 acts as an emulsifier. The mixture is shaken well and transferred to test tubes with the sample extract at different concentrations and is heated for a required period of 2 hours at a proper temperature. Absorbance is measured at a wavelength of 470 nm after every 20 minutes till there is change in color of the mixture. A blank used for this assay contains all the components except β-carotene. Inhibition of β-carotene is evaluated in percentage using the formula: (Amount of β-carotene present after 2 h/Initial β-carotene content) $\times$ 100.

Cheung et al. (2003) evaluated the antioxidant activity of edible mushrooms using the β-carotene bleaching method. Two solvents, methanol and distilled water, were used to prepare the extracts. The mushroom varieties taken for evaluation were *Lentinusedodes* and *Volvariella volvacea.* The results showed that a sample concentration of 2 mg/ml does not possess antioxidant activity in any mushroom variety. On increasing the extract concentration from 2 mg/ml to 20 mg/ml, the antioxidant activity increased in both the solvents. *Volvariella volvacea* showed higher antioxidant activity than *Lentinusedodes*. At a concentration of 4 mg/ml, *Volvariella volvacea* showed antioxidant activity of 26.3% in methanol and 31.8% in distilled water while at 20 mg/ml the activity increased to 49.6% in methanol and 64.2% in distilled water. On the other hand, *Lentinusedodes* showed antioxidant activity of 13.1% in methanol and 52.7% in distilled water at 4 mg/ml extract concentration but at 20 mg/ml concentration the activity increased to 45.8% in methanol and 75.9% in distilled water.

### 14.3.7 Inhibitory Effect against Lipid Peroxidation Induced by ABAP

The chemical compound 2, 2′-azobis-(2-amidinopropane)-dihydrochloride (ABAP) can be used to evaluate the ability of the mushroom extract to prevent oxidation of unsaturated fatty acids. The unsaturated fatty acid used for this study is linoleic acid. A solution of linoleic acid is mixed with mushroom extract. The mixture is added with ABAP and stirred well. Absorbance of the mixture is taken in a spectrophotometer at 234 nm. The solvent used for preparation of the extract is used as a blank for this study (Pryor et al. 1993). The inhibitory effect is evaluated in percentage using the formula:

$$\%\text{inhibitory effect} = \{(A_{\text{Control}} - A_{\text{Extract}})/A_{\text{Control}}\} \times 100$$

$A_{\text{Control}}$ represents absorbance of control contains linoleic acid and ABAP without sample extract while $A_{\text{Extract}}$ represents absorbance of the mixture of linoleic acid and ABAP with the sample extract.

Palacios et al. (2011) evaluated the inhibitory effect of some wild and cultivated varieties of mushroom procured from Spain. The mushroom varieties taken for evaluation were *Cantharellus cibarius, Boletus edulis, Calocybe gambosa, Craterelluscornu copioides, Lactarius deliciosus, Agaricus bisporus,* and *Hygrosphorusmarzuolus*and *Pleurotus ostreatus*. The results obtained from the study showed that ABAP increased the oxidation of linoleic acid in control up to a constant value but in the presence of mushroom extract, oxidation of linoleic acid was decreased. *Cantharelluscibarius* showed higher inhibition (74%) against oxidation of unsaturated fatty acids while *Agaricus bisporus* showed lower inhibition (10%).

### 14.3.8 Inhibitory Effect against Erythrocyte Hemolysis Caused by Peroxyl Free Radicals

The ability of mushroom extract to prevent erythrocytes from hemolysis caused by chain forming free radicals is determined according to the method given by Ng et al. (2000). According to this method, erythrocytes are separated from the blood samples of animals. The erythrocytes after proper washing and centrifugation are formed into a suspension using phosphate buffer saline of required percentage. The suspension is then added with 2, 2′-azobis (2-amidinopropane) dihydrochloride (AAPH) solution prepared in buffer. The mixture is then added with mushroom extracts at different concentrations. After giving proper reaction time and temperature, the mixture is then centrifuged. Absorbance of supernatant is observed through a spectrophotometer at 540 nm. AAPH is a compound that acts as a prooxidant as it results in formation of free radicals that form chain reactions leading to oxidation of proteins, fats, and other compounds (Miki et al. 1987). Studies have shown that mushroom extracts prepared in water show higher activity against prevention of hemolysis than extracts prepared in methanol. Water extracts showed inhibitory effects at any concentration; on the other hand, methanol extracts showed inhibitory effects at concentrations above 2 mg/ml.

### 14.3.9 Superoxide Anion Radical Scavenging Activity

Superoxide radical scavenging activity of mushroom extract is determined according to a method given by Zhishen et al. (1999). For generation of superoxide anions, a mixture of nitro blue tetrazolium (NBT), riboflavin, and methionine is illuminated for the required period of time. Superoxide anion is generated from riboflavin, which leads to formation of blue colored formazan from NBT (reduced). The mixture is added with mushroom extract. Addition of antioxidant-rich mushroom extract leads to scavenging of superoxide anion radicals and hence prevents formation of formazan from NBT. Absorbance of both blank (mixture of NBT, riboflavin, and methionine without illumination) and the sample is measured in a spectrophotometer at 560 nm. Scavenging activity is expressed in percentage (%) using the formula:

$$\text{Scavenging activity }(\%) = \{(\text{A}_{\text{blank}} - \text{A}_{\text{extract}})/\text{A}_{\text{blank}}\} \times 100$$

Mahfuz et al. (2007) studied superoxide radical scavenging activity of some mushroom varieties obtained from Turkey. Results showed that scavenging activity of *Verpa conica* (99%) was highest and *Agaricus bisporus* (71%) possesses the lowest scavenging activity.

The studies discussed above suggest that one must increase consumption of mushrooms in diet as it is a good source of antioxidants as well as prevents the process of aging and other diseases in humans. Mushroom has metal scavenging activity as metals act as cofactors for enzymes involved in increasing the rate of oxidation. However, studies on development of antioxidant-rich nutraceuticals for humans from mushroom are still underway and need proper attention in future.

## 14.4 Health Benefits

The presence of biologically active compounds having different medicinal properties provides an opportunity to develop edible mushrooms into functional foods with enhanced nutritional value and numerous health benefits. Edible mushrooms when ingested as a part of daily diet have been found to be helpful in the prevention and treatment of various diseases. Some of these health benefits are explained below.

### 14.4.1 Cancer

There has been sufficient research, which proves the role of mushrooms in the control and treatment of cancer, which is a major cause of worldwide mortalities. This was attributed to the presence of bioactive polysaccharides present in the mushrooms (Guillamón et al. 2010; Meng et al. 2016). Recently, it has been established from various studies that the intake of edible mushrooms significantly reduced the prevalence of breast cancer, but further studies are needed to corroborate the findings (Li et al. 2014a, 2014b). The mechanism of cancer prevention is proposed to be due to the immunomodulatory role played by the bioactive polysaccharides present in mushrooms. They trigger the immune system response, which facilitates the antitumor activity, thereby enhancing the defense mechanism of the host (Meng et al. 2016).

### 14.4.2 Metabolic Syndrome

Metabolic syndrome refers to that clinical condition in human beings, which comprises of disorders such as obesity, hyperglycemia, high cholesterol, and hypertension. The intake of edible mushrooms has been proven to effectively prevent the metabolic syndrome. The mushroom extracts comprising of polysaccharides and other bioactive compounds help in lowering of cholesterol levels and reducing hypertension. These bioactives include β-glucans, lectines, eritadenine, tri-terpenes, sterols, etc. (Kundakovic and Kolundzic 2013).

### 14.4.3 Obesity and Hyperlipidemia

There are various studies carried out in relation to the prevention of different cardiovascular disorders and minimizing obesity and hyperlipidemia and the risk associated with such diseases by introduction of mushrooms in the diet. Most of such health benefits are found to be helpful in reduction of sugar and cholesterol levels in the blood. The presence of other compounds including antioxidants plays an important role in lowering the levels of triglycerides (Zhang et al. 2016).

Several studies have propounded the role of mushroom intake in the prevention of hyperlipidemia and obesity. Different studies have proved *L. edodes* to effectively reduce the lipid levels and help in the prevention of weight gain, which could lead to obesity. In this study, the antihyperlipidemia activity of *L. edodes* was established by feeding rats with high-fat diet along with *L. edodes*. The fat deposition was significantly reduced along with lowering of the triacylglycerol levels in the plasma (Handayani et al. 2011). In another study, the concentration of phosphatidylcholine, which is an essential phospholipid for secretions from liver, was found to be decreased due to the presence of bioactive compound of *L. edodes*, namely, Eritadenine. It helped in the prevention of the condition of dyslipidemia (Sugiyama et al. 1995).

### 14.4.4 Hypercholesterolemia

The extracts from mushrooms are considered to be a good source of bioactive derivatives such as eritadenine, ergosterol, β-glucans, etc., which help in the inhibition of enzymes responsible for biosynthesis of cholesterol inside the body, thereby preventing various cardiovascular diseases. The intake of mushrooms as such prevents the onset of atherosclerosis as they consist of lower fat content along with high amount of fibers (Guillamón et al. 2010; Gil-Ramírez et al. 2016).

The benefits of mushrooms, especially *A. bisporus*, which is a very widely consumed mushroom, in prevention of hypercholesterolemia have been shown by many studies. Jeong et al. (2010) reported a significant decrease in the cholesterol levels and concentration of lipoproteins in the plasma of rats upon administration of the mushroom *A. bisporus* orally. The mechanism behind this health benefit was expressed by de Miranda et al. (2016) through the study on health benefits of *A. brasiliensis*. They found that the lowering of cholesterol levels in serum was linked with biochemical changes, which stimulated the biliary excretion rate of cholesterol, thereby reducing its levels in the body.

### 14.4.5 Diabetes

A lot of studies have been conducted, which showed the role of mushroom bioactives in lowering the glycemic activity in the body. Among the different varieties of genus *Pleurotus*, the extracts from *P. eryngii* were found to possess significant hypoglycemic activity. It reduced the glucose levels in the serum of mice, thereby providing an opportunity to be used as an alternative food to diabetic people (Li et al. 2014a, 2014b). Other mushroom species found to possess hypoglycemic activity and reducing the levels of glucose in the serum include *P. pulmonarius* and *P. sajor-caju* (Badole et al. 2008; Ng et al. 2015). One more mushroom genus which has been found to possess a beneficial role in case of diabetes is *Agaricus.* A lot of studies have been conducted which demonstrated the antiglycemic activity of many species of *Agaricus* (Jeong et al. 2010; Mascaro et al. 2014; Niwa et al. 2011). It was reported by Jeong et al. (2010) that the oral administration of *A. bisporus* helped in significant reduction in the lowering of glucose levels in the plasma of rats induced with type-II diabetes. The species of *Agaricus sylvaticus* (Mascaro et al. 2014) and *Agaricus blazei* (Niwa et al. 2011) are found to be beneficial in reducing the levels of glucose along with glycerol and triglycerides in the blood of rats induced with type-II diabetes, thereby providing relief during type-I diabetes. These effects were proposed to be due to the protection of glandular cells in the liver, which are responsible for the secretion of insulin.

### 14.4.6 Hypertension

High blood pressure occurs due to the effect of Angiotensin-converting enzyme (ACE), which is a main component of the renin–angiotensin system causing constriction of blood vessels. The treatment of cardiovascular diseases includes the use of ACE inhibitors, which are the main constituents of drugs for the prevention of diseases related to it. Recently, various studies have been carried out to replace the synthetic antihypertension drugs with natural compounds. In this regard, various mushroom species are explored to be used in place of synthetic antihypertension drugs. These include *G. frondosa, H. erinaceus, Hypsizygus marmoreus, A. bisporus*, etc., which can be used as alternatives for treating hypertension (Yahaya et al. 2014; Friedman 2015; Lau et al. 2014). Several bioactives in the extracts of these mushrooms inhibit the ACE's active site involving the renin angiotensin–aldosterone system, which helps in lowering hypertension (Yahaya et al. 2014). The various bioactives possessing such benefits found in the mushrooms include some peptides from *A. bisporus* (Lau et al. 2014), proteins from *P. pulmonarius* mycelium (Ibadallah et al. 2015), etc.

### 14.4.7 Neurodegenerative Diseases

Different species of mushrooms such as *Ganoderma lucidum, Sarcodon scabrosus, H. erinaceus* etc. have been studied in relation to their beneficial effects on the nervous system of humans (Sabaratnam et al. 2013)[9]. These benefits are in the form of the regulation of growth and development of nervous tissue along with the prevention and treatment of various neurodegenerative disorders. *H. erinaceus* is the most studied mushroom in this context. The different bioactives present in *H. erinaceus* stimulate the synthesis of the best neurotropic factor, i.e., nerve growth factor (NGF), which is an essential regulatory substance in the nervous system (Zhang et al. 2015). The oral administration of *H. erinaceus* has been also found to play an important role in the prevention and treatment of various neurodegenerative disorders related with the loss of progressive function of neurons, which include

Alzheimer's disease, dementia, depression, and other cognitive impairment-related disorders (Jiang et al. 2014).

### 14.4.8 Other Health Benefits

There are lot of other health benefits provided by the various bioactive compounds present in mushrooms, which include antioxidant activity, anti-inflammatory and anti-allergic properties, and antimicrobial and antiviral benefits (Zhang et al. 2016). The intake of mushrooms has been found to reduce the oxidative stress due to the presence of a wide range of antioxidants present in mushrooms, which include the different phenolics, tocopherols, ascorbic acid, carotenoids, and other polysaccharides. The different mechanisms responsible for providing antioxidant properties include free radical scavenging, inhibition of lipid peroxidation, facilitating increased antioxidant enzyme activity, etc. (Zhang et al. 2015; Kozarski et al. 2015a, 2015b).

Mushrooms contain some antiallergic compounds, which help in the stimulation of the immune system, thereby providing benefits in the prevention and treatment of various allergic diseases. Some of the examples which have demonstrated significant antiallergic effects include *P. eryngii, Pholiotanameko, H. marmoreus, and Flammulina velutipes* (Sano et al. 2002). The antiallergic effect was shown by Jesenak et al. (2014), who reported a significant reduction in the occurrence of recurrent respiratory tract infections in children.

Different studies have demonstrated the potential effects of mushroom extracts against bacterial and viral infections (Hassan et al. 2016; Zhang et al. 2016). Although there has been no report of any direct correlation with the active adsorption of virus or virucidal effect, many studies have demonstrated the inhibitory role of mushrooms in hampering the virus replication in initial stages (Faccin et al. 2007).

## 14.5 Conclusion

Consumption of mushrooms as a part of diet across the world is due to their potential nutritional properties. There is a wide range of compounds which are obtained from mushrooms with their distinct properties providing different health benefits. This makes mushrooms an interesting field of study and very useful source of bioactives for disease prevention in human beings. The use and potential health benefits of mushrooms for nutritional as well as therapeutic purposes have been explored by carrying out various studies. The different proposed effects on health include antitumor and immunomodulating effects. The edible mushrooms when ingested as a part of daily diet have been found to be helpful in the prevention and treatment of various diseases. The intake of mushrooms has been found to reduce oxidative stress due to the presence of a wide range of antioxidants present in mushrooms, which include the different phenolics, tocopherols, ascorbic acid, carotenoids, and other polysaccharides.

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# Yam

# 15

Ajay Singh, Ramandeep Kaur, Pradyuman Kumar, and Anju Tanwar

**Abstract**

Tuber crop (yam, potato, and cassava) is considered an important part of human diet. Among all tubers, yam is enriched with several nutrients and provides benefits for radiant health. It is an abode of nutrition that favors the promotion of health, as it is hypoglycemic, antioxidative, antimicrobial, hypocholesterolemic, and has immunomodulatory activities. Many of its phytoconstituents like phenols, phytic acids, glycoalkaloids, saponins, and proteins are solely accountable for the health benefits. Traditionally, yams were exploited for several medicinal practices; however, now its suitability has been extended with industrial importance and food applications as well. Yam has been potentially used as functional foods and nutraceutical ingredients for nourishing human well-being and reducing disease risk.

**Keywords**

Yam · Phytoconstituents · Antioxidant activity · Hypocholesterolemic · Functional foods

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## 15.1 Introduction

Yam (*Dioscorea* species) crop is of utmost importance for farmers, as it efficiently enhances the income of many farmers. The Caribbean Islands, Asia, Africa, South America, and the South Pacific islands are known for cultivation of yam. To a greater extent, it is cultivated mainly to get rid of the food security risks of the emerging population of the world. In West Africa, after cassava and sweet potato, it is the third most hit choice (Asiedu and Sartie 2010) with much better nutritional capacity than even cassava (Table 15.1) (Baah et al. 2009). Nutritional Potential for yam varies significantly where it contribute around 80 to 120 Kcal/100 g energy on consumption (Polycarp et al. 2012). However, yam lacks in some essential sulfur amino acids (methionine, cysteine, and tryptophan) (Bhandari et al. 2003). *Dioscorea dumetorum* yam has been reported to be high in protein with well-sequenced composition of essential amino acids in it (Polycarp et al. 2012). In contrast, consumption of *Dioscorea rotundata* in the African region led to high frequency of kwashiorkor occurrence, owing to least protein scores in that variety (Gladstone et al. 2014).

Ancient back, yam is not adopted for food purpose only, rather it possesses various medicinal features in along with its potential nutrient contribution. Various studies have proved the diverse nutrients and non-nutrients of yams, such as

**Table 15.1** Nutritional value of yam tubers

| Nutrition value | Yam tubers (100 g) |
|---|---|
| Calorific value (kcal) | 80–120 |
| Moisture (%) | 60–80 |
| Protein (g) | 1.5–6 |
| Fat (g) | 0.1–0.2 |
| Carbohydrates (g) | 15–40 |
| Ash (g) | 1.3–7.5 |
| Fiber (g) | 0.6–3.5 |
| *Vitamins (mg)* | |
| Thiamine | 0.10 |
| Riboflavin | 0.04 |
| Niacin | 0.07 |
| *Minerals (mg)* | |
| Potassium | 250–1500 |
| Phosphorous | 40–160 |
| Calcium | 6.5–116 |
| Iron | 1.5–9 |
| Copper | 0.1–0.4 |
| Sodium | 63–100 |
| Magnesium | 40–83 |
| Manganese | 0.95–3 |
| Zinc | 5.4–7.8 |

Source: Polycarp et al. (2012); Ferraro et al. (2016))

polyphenols and organic acids. Furthermore, during off-seasons, humans prefer to use yams for solving their seasonal food shortage instead of other tubers like cassava and sweet potato (Norman et al. 2012). This crop provides nearly 285 dietary calories/person/day to feed 0.3 billion humans in sub-Saharan Africa (Adejumo et al. 2013).

### 15.1.1 Botanical Description

Dioscorea (*Malvaceae*), a genus, includes more than 644 species of perennial herbaceous vines. Its native belongs to Africa, Asia, and Oceania. Among available varieties, white, bitter, and water yams are the hit choices of African inhabitant, whereas, Asian continent is availble with  Chinese and Water yam varieties. It is widely cultivated among temperate and tropical regions (Table 15.2) (Andres et al. 2017).

### 15.1.2 Morphology

Yam belongs to the family of herbaceous plants and is a woody climber with starchy rhizome. It appears rough and laborious to peel, but softens on heat. Appearance varies from dark brown to light pink. Most interestingly, it contained a soft mass, that is, "meat" of varied colors. This crop is perennial and available throughout the year. The *Dioscorea* develops strong stems, which twin through the trees with leaves of simple, coordinate, and large petioles characteristics. It bears small flowers with separated male and female parts; male shows sterile features for as long as of vegetative propagation (Coursey 1983). The growth of the plant stem reaches up to 6–12 m and appears as deep as dense mass. Bulbil is the aerial storage organ of *Dioscoreacae* family. Yam's another storage organ is its root, which is a swollen hypocotyl. The shallow (<1 m) fibrous root system concentrates within 30 cm of the topmost soil, depending on the species. The composition of environment genes plays an integral role in determining the shape and size of the tuber. The individual size of tubers may vary from a few grams to 50 kg and the length of tuber range from 2 to

**Table 15.2** Yam classification

| Types of yam | Botanical name |
|---|---|
| White | *Dioscorea rotundata* |
| Yellow | *Dioscorea cayenensis* |
| Water | *Dioscorea alata* |
| Air potato | *Dioscorea bulbifera* |
| Bitter | *Dioscorea dumetorum* |
| Chinese | *Dioscorea opposita* |
| Lesser | *Dioscorea esculenta* |

Source: Andres et al. (2017)

3 m. From commercial concerns, yam tubers are cylindrical in shape and a thick layer of cork covers it (Onwueme 1978).

Storage features are vary from species to species and can range from one to four months of storage capacity, which is mainly attributed to its chemical composition. Cultural and climatic factors employed while cultivating also govern the storage efficiency (Soibam et al. 2017).

### 15.1.3 Cultivation

The foremost requirement for any crop is land preparation; here, it can be through manual or automated means into the loosened soil. Seeds of yam tubers are planted on the smooth ground. Tuber size at the time of harvesting varies between 30 and 300 g. Seeds should be treated with thiabendazole (fungicide) and dried in the open air for about 4 hours. To prevent exposure to the sun, yam plants are about 10 cm deep in the soil and spacing depends upon the size of the set. Generally, for commercial production of the yam, spacing about 1 m × 1 m between rows and stands is recommended. Irrigation should be provided to the yam plant regularly for the first 2–4 months. The yam plants stake with the PVC pipes (1–3 m), bamboo sticks, and pruned tree branches. Depending upon the resources and requirements, plants stake individually or in groups of two or three. Harvesting of the yams plants should be done after the 7–8 months of the planting, when yellow leaves have emerged. Harvesting time also depends on the variety of yam. Around the tuber, digging is done to lose the tubers from the soil and then you could lift it and cut it from the vine. Bruising of the tubers should be avoided. According to size and quality, sorting and grading of tubers should be done. The healthy tubers, which are free from bruises, scrapes, insects, cuts, rots and nematodes, should be stored. The freshly harvested tubers are stacked and covered with a canvas tarpaulin. After that, expose the tubers at 29–35 °C temperature/90–95% relative humidity for one week. Emerging tissue and skin thickness form over the injured areas of tubers (Beckford et al. 2011; Asiedu et al. 2003).

### 15.1.4 Utilization of Yam as Traditional Food and Medicine

Yam is utilized in the form of cooked soup, flour, and as raw in the preparation of various foods. Yam powder is utilized to prepare various bakery products (Table 15.3). Yam tubers contain several phytochemical compounds including diosgenin, polyphenols, choline, allantoin, dioscorin, dioscin, mucin, carotenoids, and vitamins (C and E) (Claudius-Cole et al. 2017). Yam mucilage also provides dietary fiber and glycoprotein. Various studies reported the antioxidant activity, antimicrobial, and hypoglycemic activities of yam extracts. Yam tubers somehow favor the intestinal enzymatic efficiency and hence contribute to the production of epithelial cells (Chen et al. 2007).

The tubers also provide essential proteins and micronutrients (vitamins and minerals) and improve health. Yams also have ample amounts of thiocyanate,

**Table 15.3** Utilization of yam for various products

| Variety | Product | Reference |
|---|---|---|
| *Dioscorea alata* | Jam | Borela (2018) |
| *Dioscorea rotundata, Dioscorea alata and Dioscorea bulbifera* | Bread | Amandikwa et al. (2015) |
| *Dioscorea esculenta* | Bread | Ukpabia and Uchechukwu (2001) |
| *Dioscorea purpurea* | Bread | Hsu et al. (2004) |
| Yam | Biscuits | Idowu (2014) |
| Yam | Cookies | Apotiola and Fashakinly (2013) |
| Yam | Bread | Liu et al. (2019) |

which prevents the sickle cell anemia. This is the reason why urban population of Africa and America develop sickle cell anemia as they competitively less on yam consumption in competition to the rural inhabitants. In addition to this, raw yam and its products were also on hit consumption as a folk remedy to cure various diseases as well. Among the varieties, Chinese yam is also utilized as traditional medicine, owing to its potential to reduce blood sugar levels and treats diabetes. Further, yam boosts the human female by curing and menstrual disorders, rheumatoid arthritis, disorders, and schistosomiasis (parasitic disease). *Dioscorea batatas*, solely of Chinese origin (locally called 'Shanyao'), have the same medicinal traits. Some others, like 'Lichwurzel,' meaning 'tuber of light,' are utilized in the anthroposophist medicine (Simmonds 2006).

## 15.2 Bioactive Compounds in Yam

Bioactive compounds in yam such as polyphenols, antioxidants are secondary metabolite that provides several toxicological and pharmacological effects. These bioactive compounds are formed within the plants as well as the primary biosynthesis linked with development and growth. These phytochemicals possess numerous indispensable functions in plants, such as protecting the plants from detrimental effects, signaling of important functions, and attracting pollinators (Leng et al. 2019).

### 15.2.1 Ascorbic Acid

Ascorbic acid (vitamin C) is a heat-sensitive and water-soluble vitamin. It is abundant in fruits and vegetables. Due to its high heat sensitivity, it could be lost during cooking of vegetables. Vitamin C is present in substantial quantities in many root crops. Conversely, the amount could be decreased during cooking of roots without skins. Yam should be wisely prepared, and can provide a significant amount of the vitamin C content to the diet. The Nutritional Food Survey Committee reported that root crops such as yam and potatoes serve as the main source of ascorbic acid, contributing to 19.4% of the total requirement in the diet of the British people. Yam provides 6–21 mg /100 g of ascorbic acid. Moreover, the ascorbic acid content of potatoes is almost similar to the cassava and sweet potatoes. The proportion of vitamin C varies among the species, crop year, location, maturity, soil conditions, and nitrogen and phosphate fertilizers (Ola and Opaleye 2019).

### 15.2.2 Bioactive Protein

Bioactive protein such as dioscorin is the main storage protein present in *Dioscorea* variety of yams. In the *Dioscorea* species, it contributes to about 90% of the total protein content. Dioscorin protein has been proved to provide trypsin inhibitor activities and carbonic anhydrase. Additionally, dioscorin in the presence of glutathione participates in *monodehydroascorbate reductase* and *dehydroacsorbate reductase* reactions (Hou et al. 2001). Dioscorin also showed antioxidant activity and is further having helpful effects in dropping blood pressure (Hsu et al. 2002).

In addition to this, some clinical trials confirmed antihypertensive effect and angiotensin-converting enzyme (ACE) inhibitory action of Dioscorin as practically revealed in hypertensive rats (Lin et al. 2006). The dioscorin protein showed immunomodulatory, *monodehydroascorbate reductase, dehydroascorbate reductas*, trypsin inhibitor, and *carbonic anhydrase* activities (Liu et al. 2007).

**Diosgenin**

Diosgenin is a valued concern here; it belongs to the triterpene group that seizes chances for colon cancer from occurring, and lessens cholesterol absorption. Pharmaceutically, it is utilized in drug development, for instance, cortisone, hormonal drugs (Zhang et al. 2014). Diogenin and its glycosides are the typical bioactive compounds in the Dioscorea family. These compounds are found in Chinese yam. *Dioscorea dregeana*, *Dioscorea esculeta*, and *Dioscorea rotundata* contain diosgenin, which showed antimicrobial and anti-inflammatory activities to gram +ve and -ve bacteria (Thajunnisha and Anbazhakan 2013).

### 15.2.3 Saponins

Saponins act as natural antibodies, having numerous aqueous foaming properties, hemolytic activity, and cholesterol binding properties. Its antimicrobial traits are utilized sometimes to treating yeast and fungal infections. It has been reported that *Dioscorea bulbifera* contains saponin (Okigbo et al. 2009).

### 15.2.4 Extraction of Bioactive Compounds from Yam

Extraction of bioactive compounds is required to separate the active components from other components. Extraction method and type of solvent depend upon the type of extraction component. For the utilization of bioactive compounds in the development of nutraceuticals, pharmaceutical, as a dietary supplement, food ingredient and in the cosmetic products, extraction of the component is required. Bioactive components can be extracted from fresh, frozen, and dried plant materials (Lin et al. 2016). The method of extraction comprises conventional and modern method.

#### 15.2.4.1 Conventional Method of Extraction

Since ancient times, long soxhlet maceration and hydro-distillation are the only means for extraction. Fabricated novelty in soxhlet sense not only works for fat but also for many other phytochemical constituents. As per the present concern, maceration means of extraction of various constituents of commercial grade and healthy attributes from yarm are still adopted as an inexpensive mean.

Hydro-distillation was developed long ago and it has the same significance of extraction for bioactive cum phytoconstituents. Extracted essential oils, on the basis of method adopted, are divided into three classes: water distillation, steam distillation, and direct steam distillation. Hot water and steam are used as the main solvents to extract bioactive compounds from yam. These straight methods utilized for yam in assistance with phenol were analyzed and quantified by Eleazu et al. 2013.

#### 15.2.4.2 Modern Methods of Extraction

These methods were developed due to the several disadvantages of the traditional method of extraction. It comprises surfactant-mediated techniques, solid-phase extraction, microwave-assisted extraction, pressurized-liquid extraction, supercritical-fluid extraction, and solid-phase micro-extraction (Sasidharan et al. 2011). Shah and Lele (2012) extracted Diosgenin from *D. alata* by acidic hydrolysis of the glycosides, followed by the HPTLC analysis. Several techniques and solvents are used for the extraction of polyphenols from plants. The technique which is used for the isolation of phenolic compounds from plant material mainly depends on the type of polyphenolic compound.

## 15.3 Bioactivities of Phytochemicals in Yam

### 15.3.1 Antioxidant Activity

The various research studies reported that antioxidant compounds in yam play an important role in the prevention of ageing, diabetes, arthritis, neurodegenerative and autoimmune disorders, cardiovascular, and carcinogenic diseases. The internal antioxidant defense system of the body comprising enzymes (*Catalase, superoxide dismutase and glutathione peroxidase*) and other compounds (glutathione, tocopherol, vitamin C, uric acid, and lipoic acid) provides protection to the body. However, when the body is exposed to highly oxidative stress, external sources of antioxidants are required. Various studies reported the antioxidant activities of roots and tuber crops (Liu et al. 2016).

Cornago et al. (2011) reported the total phenolic and antioxidant activities of Philippine yams (lesser and purple yam). Lesser yam (*Dioscorea esculenta*) and purple yam (*Dioscorea alata*) contained 69.9 to 421.8 mg GAE/100 g db of a total phenolic content. The purple yam variety showed the highest total phenolic and antioxidant activities as compared to other varieties. Antioxidants were determined in terms of DDPH, ferrous ion-chelating activity and reducing power assay.

Hsu et al. (2011) reported the antioxidant activity of ethanolic and water extracts of yam peel on tert-butyl hydroperoxide (t-BHP). This encouraged oxidative stress in mouse liver cells (Hepa 1–6 and FL83B). Ethanolic extracts of yam peel showed more protection on t-BHP-treated cells as compared to water-extracted antioxidants. Moreover, ethanolic extract had high catalase activity as compared to water extract.

Heating affected the antioxidants, phenolics, and the stability of dioscorin in the yam. Raw yams contained more bioactive compounds as compared to cooked yams. Moreover, the DPPH radical scavenging activities dropped with elevation in the temperature. In yam cultivars, phenolics and dioscorin content correlated with ferrous ion-chelating effect and DPPH radical scavenging activity. The phytocompounds present in the yams proved to increase the activities of endogenous antioxidant enzymes. Yam has been proved to reduce the levels of triacylglycerol, γ-glutamyl transpeptidase (GGT), and low-density lipoprotein. Yam also enhances the antioxidant activities of hepatic enzymes such as superoxide dismutase and glutathione peroxidase (Chan et al. 2010).

### 15.3.2 Antimicrobial Activity

The antimicrobial potential of various varieties of yam is due to the presence of phenolic compounds. Sonibare and Abegunde (2012) recorded that the methanol extracts of Dioscorea yams (*Dioscorea dumetorum* and *Dioscorea hirtiflor*a) had higher amounts of both antioxidant and antimicrobial compounds. The determination of antimicrobial activity was done by the agar diffusion method (for bacteria) and for fungi, pour plate method was preferred. Also, *D. dumetorum* reported the highest in vitro antibacterial activity against *Proteus mirabilis*. The methanolic extracts of *D. hirtiflora* showed antimicrobial activity against *Penicillium chrysogenum, Aspergillus niger, Candida albicans, Salmonella typhi,* and *Staphylococcus aureus*.

**Hypocholesterolemic Activity**

Worldwide, cardiovascular diseases are the primary causes of death. It has been proved that diet plays a vital role in the prevention of cholesterol homeostasis. Diosgenin, a steroidal saponin of yam, showed hypolipidemic and antioxidative activities. Diosgenin exhibited decreased total cholesterol level, protective effect on liver under high-cholesterol diet, pancreatic lipase inhibitory activity, and prevented the oxidation of polyunsaturated fatty acids (Son et al. 2007).

Hypercholesterolemic rats were fed with yam (Dioscorea) which showed that diosgenin decreases the absorption of cholesterol, increases synthesis of hepatic cholesterol, and secretion of biliary cholesterol without effect on the level of serum cholesterol. In agreement with this finding, many studies showed that diosgenin, in some varieties, decreases absorption of intestinal cholesterol (Uchida et al. 1984).

Furthermore, diosgenin stimulated fecal cholesterol excretion which was primarily attributed to its impact on hepatic cholesterol metabolism rather than intestinal cholesterol absorption (Temel et al. 2009).

Native protein of dioscorin purified from *D. alata* (cv. Tainong number 1) (TN1-dioscorin) and its peptic hydrolysates presented ACE inhibitory activities in a dose-dependent manner. With kinetic analysis, it has been reported that dioscorin displayed a mixed non-competitive inhibition against ACE. High blood pressure could be controlled with dioscorin from Dioscorea (Temel et al. 2009). Yam as a source of dietary fiber prevents the absorption of fat in the intestine, thus resulting in lowering of LDL.

### 15.3.3 Immunomodulatory Activities

The immune system requires attention, as it is associated with the several chronic diseases. Immunomodulation includes suppression or stimulation of human immune functions. The immune system contains the macrophage, lymphocytes, and dendritic cell, natural cell killer.

Yam dioscorin protein exhibited the in vitro immunomodulatory activities. The dioscorin has effect on native BALB/c mice spleen cell proliferation, which was examined through MTT assay. This was observed that dioscorin in the absence of lipo-polysaccharide encouraged RAW 264.7 cells to produce nitric oxide. Yam dioscorin showed immunomodulatory activities through the innate immunity that protects the host from infection by the other organisms. Dioscorin was found to encourage production of cytokine and to improve phagocytosis (Liu et al. 2007).

Various studies have proved the immune activity of yam mucopolysaccharides. In the presence of mucopolysaccharides, in vitro cytotoxic activity of mouse splenocyte against leukemia cell was improved. Additionally, in the mucopolysaccharides, the release of IFN-γ was significantly increased and showed their ability of inducing cell-mediated immune responses. The mucopolysaccharides at a concentration of 50 μg/mL enhanced lysosomal phosphatase activity and uptaking capability of peritoneal macrophages (Choi et al. 2004).

Chen et al. (2003) recorded the effects of Taiwan's yam (*Dioscorea alata*) on mucosal hydrolase activity and metabolism of lipids. High level of Tainung yam in the diet (50% w/w) decreased plasma and hepatic cholesterol proportions, but, in mice model, increased fecal steroid excretions. This could happen owing to the bile acid loss in the enterohepatic cycle to fecal excretion. Further, Tainung yam fiber decreased absorption of fat, cholesterol, and bile acid. Tainung yam's short-term consumption (25% in the diet for 3-weeks) could reduce an atherogenic index but no effect on total cholesterol level in non-hypercholesterolemic mice was reported.

Aside from this, some additional dietary yam (50% yam diet) can exert consistent hypocholesterolemic effects. However, in this study, diosgenin was not interpreted, and authors also believed that diosgenin may not be involved in the cholesterol-lowering effect of Tainung yam. Bioctive components such as dietary fibers and viscous mucilage can be beneficial for lowering cholesterol. Furthermore, in mice, 25% of uncooked Keelung yam's short-term consumption (3 weeks) can effectively decrease blood cholesterol levels. Authors elucidated that the active components for lowering lipid effects may be attributed to dietary fiber, mucilage, plant sterols, or synergism of these active components.

### 15.3.4 Hormonal Activities

In postmenopausal women, yam (Dioscorea) has the capacity to decrease the risk of cardiovascular diseases and cancer. It was found that the serum estrogen and sex hormone-binding globulin (SHBG) levels hiked gradually with the regular consumption of Yam. Moreover, serum hormone parameters namely, estrogen, estradiol, and SHBG were measured, surprisingly values did not vary in those who were fed with sweet potatoes as compared to control. The risk of breast cancer with increase in estrogen levels may be controlled by the increased SHB and the ratio of estrogen and estradiol to SHBG. Further, studies showed that higher SHBG levels had a counter effect against the occurrence of several coronary heart diseases and Type 2 diabetes mellitus in women (Wu et al. 2005).

During menopause, enhancement in bone strength with the consumption of Dioscorea was found, and also in bone remodeling and osteoporosis. Administration of Dioscorea decreased the pores in bones and increased the ultimate strength of bones (Chen et al. 2008).

## 15.4 Storage of Yam Tubers

Yam tubers are living organisms and, therefore, they breathe continuously during storage. During respiration process, tuber starch is oxidized and carbon dioxide, water, and heat are produced, resulting in reduction of dry matter. Among the main tuber crops, yam is highly perishable and requires good storage conditions (Opara 2003). Healthy and sound yams are selected, and then curing combined with fungicide should be done. Ventilation in the storage room is required to remove the heat produced by respiration reaction. During storage of yam, regular inspection should be done to remove rotten tubers (Oke 1990). The best storage temperature for yam storage ranges from 14 to 16 °C with 70–80% relative humidity (Chou et al. 2006). In Africa, yam post-harvest losses are very high due to lack of proper storage conditions, as well as insects also cause 25% harvest loss within four months,

## 15.5 Effect of Processing on Nutritional Quality of Yam

Yams are commonly grown for direct consumption. Yam tubers are having seasonal growth cycle. Yam is grown in the rainy season and after harvesting, problem arises regarding storage due to poor storage system which results in scarcity after a few months (Opara 2003). As discussed above, yam storages are a serious concern. In Nigeria, yam has become unaffordable and expensive in urban areas as the great loss of yam after harvesting. Moreover, farmers sell the product immediately after harvest to avoid losses, and hence results in low income and less profits. Therefore, there are numerous restraints to the yam industry (Kleih et al. 2012).

Yam flour, pellets, chips, and starch are currently produced by traditional and industrial methods (Fig. 15.1). For the preparation of chips, yam tubers are peeled, cut into pieces, and parboiled. During parboiling yam is kept in water for 1–4 days. Natural fermentation takes place during this period. After that, yam is dried under sun and chip are prepared that can be further milled into flour (Ojokoh and Gabriel 2010). For the yam-derived products, there is not yet a specification standard (Codex Alimentarius 2005). Yam flour can be reconstituted with hot water to form dough and paste known as kokonte and amala among people of Ghana and Nigeria, respectively. The amala is a popular food in Nigeria. Yam flour can be fortified

**Fig. 15.1** Flow process for yam flour and yam chips

**Yam Tubers**
⇩
**Cleaning/Washing**
⇩
**Peeling**
⇩
**Cutting into Slices**
⇩
**Curing**
⇩
**Fermentation**
⇩
**Sun Drying**
⇩
**Yam chips**
⇩
**Milling**
⇩
**Yam Flour**

**Table 15.4** Effect of processing on the properties of yam flour

| Variety | Processing method | Effect | Reference |
|---|---|---|---|
| Dioscorea dumetorum, Dioscorea alata, Dioscorea alata, Dioscorea cayenensis | Dried under three drying methods (oven, solar and sun drying methods) | Acts as stabilizers or modifiers to enhance product, improves rheological properties | Okeke-Oluka (2018) |
| Dioscorea rotundata and Dioscorea alata | Sun and oven-drying | High water-binding capacity, reduces the peak viscosity, holding strength, final viscosity, set back and elasticity | Jimoh et al. (2009) |
| Dioscorea rotundata | Blanching temperature and soaking time | Blanching and soaking of fresh yam cubes Resulted in significantly higher protein content, carbohydrate content, swelling capacity, foaming capacity, and bulk density and has better quality attributes than the control sample | Adejumo et al. (2013) |
| Yam | Blanching and drying | Total phenol content and the brown index of flour increased | Akissoe et al. (2003) |

with other flours, for instance, soya, plantain, and wheat, in order to enhance its nutritional value (Abulude and Ojediran 2006). It has been observed that in the developing countries, there is a lack of supply of instant yam flour, resulting in a high need for ready-to-use and hygienically well-packaged products that are still inaccessible in many areas of African countries.

There are several hydrothermal techniques like boiling, frying, baking, and roasting, dehydration, and fermentation under which yams are processed before consumption. These methods affect the nutritional and functional value of yam (Table 15.4).

Fang et al. (2011) discovered the abundant phenolic compounds in Chinese purple yam and various changes during vacuum frying. Anthocyanin value after vacuum frying and blanching reported was 63% and 40%, respectively. Apart from this, hydroxycinnamic acids (sinapic acids and ferulic acids) showed higher stability than anthocyanins. Phenol content was not influenced by short freezing time. Several dehydration procedures were used to produce yam flours, which could further affect their antioxidant properties. The strongest antioxidant activities were reported in freeze-dried yam flours in comparison to drum-dried yam flours or hot air-dried (Chen et al. 2008).

Chen and Lin (2007) also found that temperature negatively affects phenol, dioscorin, and antioxidant content of yam products. Chen et al. (2008) further reported impact of pH on phenols, antioxidants, and dioscorin stability in various yam tubers. At pH 5, total phenols recorded were the highest, which further decreased with gradual increase in the pH. For phenols, similar trend was found in terms of DPPH radical scavenging activity of yams at pH 5, but chelating capacity of ferrous ion was found to be high at pH 8 for all yams.

## 15.6 Safety Concern for Yam

Pesticides, heavy metals, and mycotoxin are high safety concerns. In developing countries, accurate data on the amount and use of pesticide for major cropping systems are rarely available (Williamson et al. 2008). Highly inefficient practices include poorly maintained and non-calibrated equipment, timing and targeting of application, incorrect dosage and the usage of inappropriate products.

In recent years, the utilization of yam-derived food products is rising and the accurate assessment for the metal contamination in the resulted yam products, as well as through the food manufacturing, is essential (Shin et al. 2013). The level of heavy metals is different depending on the growing area. In some parts of Africa, be 0.11 and 0.10–0.20 mg/kg of cadmium concentration in yam has been reported by the EU and WHO, respectively, whereas Pb was not detectable and Ni should be lower than 0.5 mg/kg in the most foods (IARC 1990).

Aflatoxin contamination of yam is very common due to the high moisture content. These molds affect nutrient contents of the food and produce mycotoxins which cause serious health hazard to humans and animals (Djeri et al. 2010). Due to inadequate storage facilities, contamination occurs (Adebayo-Tayo et al. 2006). Pathogenic molds detected in yam were *Rhizopus nodosus, Trichoderma viride, Penicillium oxalicum, Rhizoctonia, Penicillium chrysogenum, Fusarium solani, Fusarium oxysporum, Botryodiplodia theobromae, Aspergillus niger* and *Aspergillus flavus* (Aidoo 2007). Yam flour is commonly contaminated by the species of Penicillium, Rhizopus, Mucur and Aspergillus, whereas Fusarium in the case of yam chips. Among 18 different types of aflatoxins that have been identified, major ones are aflatoxin B1, B2, G1, and G2, where aflatoxin B1 is the most toxic and causes cancer in human. Occurrence of aflatoxin B1 has been identified in some food commodities including maize flour, cassava flour, and yam chips. The Codex Alimentarius Commission fixed the concentration above the tolerance level of 15 mg/kg total aflatoxin (Somorin et al. 2012).

## 15.7 Conclusion

For humans, yam is the one of the most important components of diet that provides energy and bioactive compounds. These bioactive compounds exhibit excellent antioxidative, anti-mutagenic, anti-inflammatory, and anti-carcinogenic properties. Various kinds of foods could be prepared with yam, and its usage varies among different countries and regions. Different properties such as the nutritional and functional properties are affected with processing of constituent compounds. Yam might act as a functional and nutraceutical ingredient to combat non-communicable chronic diseases and to enhance wellness.

On the other side, post-harvest losses of yam are the major issue in African countries, although the peeled and other waste of yam is mainly utilized for feeding poultry and livestock. The losses related to the crop threaten food security, affect the potential income of the farmers, and worsen conditions of poverty among rural households. In the developing countries, one of the greatest challenges of food industries is the conversion of traditional processing methods into modern industrial operations. Traditional means of yam based product utilization vary among the geographical locations all around the world and is mainly due to available variety, consumption habits, and through adopted processing methodological terms too. Therefore, there is need to develop highly efficient techniques for the proper utilization of yam in various products and resolve the issue of food security.

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# Leek (*Allium ampeloprasum* L.) 16

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**Abstract**

Leek (*Allium ampeloprasum L.*) is one of the most popular vegetables cultivated all over the world, and it belongs to the family Amaryllidaceae/Alliaceae. The *Allium ampeloprasum L.* is categorized into wild leek, cultivated leek, kurrat, pearl onion, taree and great-headed garlic based on their diverse cytogenetic and morphological characters. Leeks are known for their characteristic flavours and medicinal value. Leeks have excellent nutritional properties and are a rich source of bioactive compounds and phytochemicals. Leeks are rich in indietary fibres; fructans; PUFA, predominantly linoleic acid; various amino acids, mainly glutamine, glutamic acid, aspartic acid, arginine and alanine; and organic acids like ascorbic acid and malic acid. The bioactive compounds and phytochemicals like S-alkyl-L-cysteine sulphoxides, polyphenols, saponins, kaempferol glycosides, β-carotene, pectic polysaccharides and tocopherols are responsible for various health benefits. These phytochemicals have excellent antioxidant and potent anticarcinogenic properties which help in the reduction of colorectal, stomach and breast cancers. Consumption of leeks causes a reduction of the risk of hypercholesterolemia, blood pressure, arteriosclerosis and platelet aggregation which helps in the prevention of cardiovascular diseases. Besides these, the leeks have antimicrobial activity against various bacteria and fungi and viruses.

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**Keywords**

Leek · Nutritional properties · Bioactive compounds · Processing effect · Health benefits

## 16.1 Introduction

Leek (*Allium ampeloprasum L.*) is categorized under the genus *Allium*. It is the most important ancient vegetable crop cultivated worldwide. It belongs to the family Amaryllidaceae/Alliaceae of monocotyledonous species. A complex of different cyto- and morpho-types of leek form an *Allium ampeloprasum L.* species complex and is widely distributed all over the world. The complex includes groups of cultivated leek, kurrat, pearl onion, taree and great-headed garlic. After cooking leek is eaten as in soups, fried or mixed with other ingredients, but leek can also be consumed in raw as a fresh state in salads. It is also used as an ingredient in many food preparations and preservation and for improvement of flavour and nutritional quality of many food dishes. It is mainly grown for its leaves and blanched stem. The mature leek contains some starch and appreciable quantities of dietary fibres, carbohydrates, proteins, minerals, bioactive phytochemicals, antioxidants and vitamins A, B and C. The leek has been used for a wide range of diseases. The literature of leek shows that leek has some pharmacological activities such as antidiabetic, anti-inflammatory, hypolipidaemic, anticarcinogenic, antimicrobial, free radical scavenging, antihelmintic, diuretic, antihypertensive and digestive properties. Processing of leeks such as post-harvest processing, cutting, blanching, tampering, cooking, fermentation and storage is significantly affecting the nutritional component, biologically active compound and ultimately biofunctional properties of leek (Dogan Dogan 2012; Dey and Khaled 2015; García-Herrera et al. 2014).

### 16.1.1 History

The leek is known to be originated from *Allium ampeloprasum L.* which is widely spread from Portugal to western Iran of the Mediterranean Basin. Its minor crops are locally cultivated from Asia to Iran and the Caucasus and infrequently in California and other areas of Europe and America. Leeks are cultivated since very early times with ancient popularity when the Egyptians built pyramids. It is also believed to be a chief vegetable of the Greeks and Romans that spread subsequently throughout middle-age Europe. Leeks have a long and affluent history and are appreciated mostly by ancient Egyptians, Greeks and Romans due to the valuable health effects. The Roman emperor Nero used to eat leeks as a daily diet to make his voice tougher, while the Greek philosopher Aristotle has also credited the strong voice upon eating of leek diet. The Romans have introduced leeks to the United Kingdom where it grew due to the ability to withstand cold weather. Nowadays, leeks are grown up in many European nations as an important crop and as part of northern European cuisines (Aedo 2013).

### 16.1.2 Production

Leeks are the most important vegetable crop cultivated in the world, especially in Western Europe, and mainly grown in a home garden, greenhouse as well as in open field on a big farm. It can easily adapt to different ecological conditions, and thus the cultivation spreads all over the world. Worldwide production and cultivation area of leeks and other alliaceous vegetables are given in Table 16.1. According to the most recent data given by the United Nations Food and Agriculture Organization, the leek is produced worldwide, and its production is approximately 2,179,050 tonnes, and it is cultivated on area of 137,791 ha in 2017. Leeks are mostly cultivated in Europe and Asia and less often in southern Asian country group (India, Pakistan Sri Lanka, Bhutan, Nepal and Bangladesh) having very less production as well as cultivation area. In India and Sri Lanka, it grows well at higher altitudes, but humid conditions are not good for its production. In India commercial cultivation of leek is not followed, and it grows mainly in the kitchen garden (FAOSTAT 2018; Swamy and Gowda 2006).

### 16.1.3 Botanical Description

The genus *Allium* includes about 750 species and is in fair agreement with a record of the World Checklist of Selected Plant Families (Kew Science 2020), which classifies 860 species of *Allium*. The modern intrageneric classification splits the genus *Allium* into 15 subgenera and 72 sections. The subgenus *Allium* is the largest, including around 280 species, 114 of which comprise its main section, *Allium*. An informal classification of this subgenus into different groups; the species complex group of *Allium ampeloprasum L.* and garlic. A species complex of *Allium ampeloprasum L.* formed due to the difference in cyto- and morpho-types in leeks and is widely distributed either in the wild or domesticated range adjacent to the Mediterranean Sea, Mediterranean islands, and across from North Africa and Southwest Asia to South England. *Allium ampeloprasum* complex includes groups of wild leek, cultivated leek, kurrat, pearl onion, taree and great-headed garlic (elephant garlic). The great-headed garlic forms bulbs and cloves similar to garlic, but size,

**Table 16.1** Production and cultivated area of leeks and other alliaceous vegetables

| Region | Tonnes | Area, ha |
|---|---|---|
| Worldwide | 2,179,050 | 137,791 |
| Europe | 807,061 | 30,006 |
| Western Europe | 558,765 | 15,372 |
| Southern Europe | 157,394 | 6334 |
| Eastern Europe | 112,556 | 6712 |
| Asia | 1,314,426 | 90,079 |
| Southern Asia | 66,078 | 2614 |

Source: FAOSTAT (2018)

number of cloves per bulb and flavour are markedly different. The species complex is categorized by their ploidy levels, and the polyploid series are $2n = 24, 32, 40, 48$ or 56. However, tetraploids and hexaploids are predominant in wild populations. The species complex is surrounded by arguments concerning atypical meiotic behaviour and genome makeup, features that make it very exciting to study (Friesen et al. 2006; Guenaoui et al. 2013). The taxonomical classification of the leek is given below. It is variously classified as *Allium ampeloprasum*, *Allium porrum*, *Allium ampeloprasum* var. *porrum*, *Allium ampeloprasumporrum* or *Allium ampeloprasum* (GRIN 2008).

**Kingdom:** Plantae
**Clade:** Angiosperms
**Clade:** Monocots
**Order:** Asparagales
**Family:** Amaryllidaceae
**Subfamily:** Allioideae
**Genus:** *Allium*
**Species:** *Allium ampeloprasum*

The most public names of leeks in various languages are leek in English; jiucongin in Chinese; poireau and porreau in French; porreein in German; porro and porrettain in Italian; liikiin in Japanese; lukporejin in Russian; and ajoporro and apuerro in Spanish (Swamy and Gowda 2006).

### 16.1.4 Nutritional Properties

Leek is a good source of carbohydrates, proteins, fat, dietary fibre and K, Ca, Mg, Na and Cu mineral components (Table 16.2). The total available carbohydrate composition is 0.5 to 16.60 g/100 g. The wild leek variety has higher carbohydrates than other wild leafy vegetables. The average protein content is 1.5 to 2.1 g/100 g. Among the amino acids of leek, glutamine, glutamic acid, aspartic acid, arginine and alanine are present in a higher amount (Najda et al. 2016). More than 20 distinct fatty acids are found in edible parts of the leek. The fatty acids, namely, linoleic, palmitic, oleic and α-linolenic acid, are reported to be 46–53, 20–23, 4–13 and 3–7%, respectively, and they make up to 80% of the total lipids present. Saturated fatty acids are 38.23 to 40.0% of total fatty acids, and palmitic acid is the major one, i.e. 26.42%. PUFA is around 54.16 to 79.04% of total fatty acids. Leek is a good source of potassium, iron and selenium. Leek contains 30.24 to 81.7 mg/100 g of Ca and 0.20 to 2.1 mg/100 g of Fe. In addition to that, Mg, Na, P and Cu are 10–28, 5–54.6, 35 and 0.06–0.30 per 100 gm of leek (García-Herrera et al. 2014; Koca and Tasci 2015).

**Table 16.2** The nutritional profile of leek

| Proximate composition | Leek (*Allium ampeloprasum* var. *porrum*) | | | |
|---|---|---|---|---|
| | Van der Meer and Hanelt (1990) | Souci et al. (2000) | García-Herrera et al. (2014) | USDA (2018) |
| Moisture (%) | 90 | 86 | 78.32 | 83 |
| Total available carbohydrates (%) | 5 | 6.75 | 16.6 | 14.2 |
| Proteins (%) | 2 | 2.1 | 1.67 | 1.5 |
| Lipids (%) | 0.3 | 0.1 | 0.18 | 0.3 |
| Fibre (%) | Nd | 2.9 | 4.23 | 1.8 |
| Energy (kcal/100 g) | Nd | Nd | 78.92 | 61 |
| Ashes (%) | 1.5 | Nd | 0.79 | Nd |
| **Minerals** (mg/100 g) | | | | |
| K | 250 | Nd | 309.37 | 180 |
| Na | 5 | Nd | 54.6 | 20 |
| Ca | 60 | 63 | 70.16 | 59 |
| Mg | Nd | Nd | 14.03 | 28 |
| Mn | Nd | Nd | 0.11 | Nd |
| Fe | 1 | 0.81 | 0.6 | 2.1 |
| Zn | Nd | Nd | 0.75 | 0.1 |
| Cu | Nd | Nd | 0.11 | Nd |
| P | Nd | Nd | Nd | 35 |
| **Vitamins** (mg/100 g) | | | | |
| Total vitamin C | 25 | Nd | 6.69 | 12 |
| Thiamin | Nd | Nd | Nd | 0.060 |
| Riboflavin | Nd | Nd | Nd | 0.030 |
| Niacin | Nd | Nd | Nd | 0.400 |
| Vitamin B6 | Nd | Nd | Nd | 0.233 |
| Folate, DFE (μg/ 100 g) | Nd | Nd | Nd | 64 |
| Vitamin A, RAE (μg/ 100 g) | Nd | Nd | Nd | 83 |
| Vitamin A, (IU/ 100 g) | Nd | Nd | Nd | 1667.0 |
| Vitamin E | Nd | Nd | 0.05 | 0.9 |
| Vitamin K (phylloquinone) (μg/ 100 g) | Nd | Nd | Nd | 47.0 |

## 16.2 Bioactive Components of Leeks

*Allium* genus is known as a rich source of bioactive compounds, which have interesting health encouraging properties and biological activity. These are additional nutritional elements and include organosulphur compounds like isoalliin, methiin and S-alk(en)yl-L-cysteine sulphoxides (ACSOs) and compounds such as fructans, lutein, β-carotene, ascorbic acid, tocopherols, steroidal saponins, phytosterols and polyphenols like flavonol glycosides and ferulic acid (Muir et al. 2007; Nishimura et al. 2016).

### 16.2.1 Organosulphur Compounds

*Allium* species are well known to produce organic sulphur compounds also known as S-alk(en)yl-L-cysteine sulphoxides (ACSOs). In *Allium* species about 75% of the sulphur present in the storage form γ-glutamyl-ACSOs (γ-glutamyl peptides). In leeks, four different ACSOs have been found which are MCSO or methiin, 1-PECSO or isoalliin, PCSO or propiin and 2-PECSO or alliin, but only methiin and isoalliin are present in significant quantity, while propiin and alliin are present in trace quantity (Table 16.3). Plenty of volatile compounds of distinct odour like that of garlic are formed instantly after crushing the tissues of leek due to degradation of the S-alk(en)yl-L-cysteine sulphoxides by the action of alliinase enzyme (Bernaert et al. 2012b; Lundegardh et al. 2008).

### 16.2.2 Polyphenols

In leeks, the different polyphenolic compounds are present such as propyl gallate, ferulic acid, caffeic acid, sinapinic acid, luteolin, kaempferol, kaempferol 3-O-glucoside, quercetin, quercetin 3-O-galactoside and naringenin. The total phenols, flavonoids and flavanols of the whole leek, body parts of leek and essential oils (EO) of the leek are reported in Table 16.4 (Bernaert et al. 2012a, 2013b; Mnayer et al. 2014; USDA 2010; Vandekinderen et al. 2009).

The concentration of polyphenolic compounds of the leek body parts is presented in Table 16.5, among them kaempferol 3-O-glucoside, quercetin 3-O-galactoside and ferulic acid which are the main phenolic components of leeks.

### 16.2.3 Ascorbic Acid

The *Allium* species contain good amount of ascorbic acid, which is present in both the forms L-ascorbic acid (AA) and L-dehydroascorbic acid (DHAA). The L-ascorbic acid form is the biologically active form of vitamin C, but along with

**Table 16.3** The chemical structure of ACSOs of leek species

| Chemical name | Chemical formula | Common name |
|---|---|---|
| S-methyl-L-cysteine sulphoxide | R = $CH_3$ | Methiin |
| S-propyl-L-cysteine sulphoxide | R = $CH_2CH_2CH_3$ | Propiin |
| S-(2-propenyl)-L-cysteine sulphoxide | R = $CH_2CH = CH_2$ | Alliin |
| Trans-S-1-propenyl-L-cysteine sulphoxide | R = $CH = CHCH_3$ | Isoalliin |

Source: Bernaert et al. (2012b)

**Table 16.4** Polyphenol content of the different types of leek and its body parts

| Leek body part | Total phenols mg GAE 100 $g^{-1}$) | Flavonoids (mg CE 100 $g^{-1}$) | Flavanols (mg 100 $g^{-1}$) | References |
|---|---|---|---|---|
| Whole leek (fw basis) | 41.6 ± 4.0 | 10.10 ± 1.02 | 1.01 ± 0.09 | Ninfali et al. (2005) |
| | 47 | Nd | Nd | USDA (2010) |
| | 22 | Nd | Nd | Proteggente et al. (2002) |
| | 38–56 | Nd | Nd | Vandekinderen et al. (2009) |
| Wild leek (fw basis) | 57.7 | 0.86 | Nd | García-Herrera et al. (2014) |
| Green leaves (dw basis) | 50–140 | Nd | Nd | Bernaert et al. (2012a) |
| White shaft (dw basis) | 50–150 | Nd | Nd | Bernaert et al. (2012a) |
| EO of leek | 107.9 ± 0.53 | Nd | Nd | Mnayer et al. (2014) |
| GHG-L leaves | 10.73 | 6.5 | Nd | Najda et al. (2016) |
| GHG-L bulb | 20.21 | 2.64 | Nd | |

**Table 16.5** Polyphenolic compounds found in green leaves and white shaft of leek

| Polyphenol | Green leaves | White shaft |
|---|---|---|
| Propyl gallate | 2.09 ± 0.02 | 2.11 ± 0.01 |
| Ferulic acid | 27.07 ± 1.43 | 29.71 ± 0.39 |
| Caffeic acid | 0.93 ± 0.03 | 1.03 ± 0.06 |
| Sinapinic acid | 3.76 ± 0.20 | Nd |
| Luteolin | 0.74 ± 0.02 | 0.71 ± 0.01 |
| Kaempferol | 0.85 ± 0.05 | 0.77 ± 0.01 |
| Kaempferol 3-O-glucoside | 31.92 ± 2.66 | 3.50 ± 0.12 |
| Quercetin | 2.67 ± 0.04 | 2.63 ± 0.02 |
| Quercetin 3-O-galactoside | 21.73 ± 0.1 | 23.23 ± 0.13 |
| Naringenin | Nd | 0.16 ± 0.00 |

Bernaert et al. (2013b)

this DHAA also shows biological activity. DHAA is easily transformed into AA in the human body. The ascorbic acid readily neutralizes nitrogen species (RNS), reactive oxygen species (ROS), singlet oxygen and hypochlorite and helps to reactivate tocopherols and glutathione. Leek contains 2.37–12 mg/100 g of vitamin C. In leek, the AA level varies according to the different body parts, and the green leaves have higher AA content than the white shaft. The AA of white shaft varies from 0.89 to 3.55 mg AA $g^{-1}$dw, and that of green leaves varies from 2.77 to 8.52 mg AA $g^{-1}$dw (Bernaert et al. 2012a; García-Herrera et al. 2014).

### 16.2.4 Saponins

Saponins have attracted increasing attention because of their anti-inflammatory, antimicrobial, antidiabetic, platelet aggregation, inhibitor and gastroprotective property, antitumour effects and antitussive actions (Fang et al. 2015; Sadeghi et al. 2013a). Different steroidal saponins, spirostane glycosides and cinnamic acid derivatives are isolated from a different variant of leek. From *Allium porrum* steroidal saponins neoporrigenins A and B are isolated; the three new steroidal saponins named yayoisaponins A–C are found composed with agigenin, diosgenin, β-chlorogenin and 24-ethylcholesta-(6-acyl)-3-O-β-D-glucoside. From the bulbs of *Allium ampeloprasum* var. *porrum*, a new steroidal saponin is isolated, and its structure is established using NMR spectroscopy (Adão et al. 2011; Uchida et al. 2009).

### 16.2.5 Organic Acids

The total organic acid content of leeks is 310 mg/100 g. The malic acid is major organic acid of wild leek, and it is present at about 132.86 mg/100 g, followed by oxalic acid, glutamic acid, citric acid and succinic acid present at nearly 91.65, 51.67, 38.86 and 2.14 mg/100 g, respectively (García-Herrera et al. 2014; Kirk-Othmer 2007).

### 16.2.6 Polysaccharides

Leek contains 3 to 10% fructans (based on fresh mass), and apart from fructooligosaccharides, α-galacto-oligosaccharides, in the form of raffinose and stachyose, are present, and they are about 0.96% and 0.24% of the fresh mass of leek, respectively. *Allium* are rich in pectic polysaccharide (1 → 4)-linked galacturonic acid. Leeks contain glucuronic acid (1.1 to 37.5 mol%), galactose (13.3–26 mol%) and rhamnose (2.77–14.13 mol%). A novel glucofructan having a gastroprotective property is identified using Sephacryl S-300 HR high-resolution chromatography (Malafaia et al. 2015; Peshev and Van den Ende 2014).

### 16.2.7 Linoleic Acid

In leek lipids, PUFA is the major fraction present around 54.16 to 79.04%, and the ratio of PUFA and SFA is more than 0.45, which is assumed as beneficial for health (García-Herrera et al. 2014; USDA 2018).

## 16.3 Bioactive Properties

Leek like other *Allium* provides interesting nutrients, phytochemicals and other bioactive compounds to the human diet. Nutritional composition of leeks varies according to species, temperature, rainfall, sunlight, soil properties, growing conditions and the contact of other plants or animals in the system. The composition of leek also varies according to the crop's body part such as leaves and pseudostem, and these parts are mainly consumed and used in many food preparations (Bernaert et al. 2012a; García-Herrera et al. 2014).

### 16.3.1 Antioxidant Activity

Plant and vegetable origin bioactive compound acts as antioxidants due to their free radical scavenging and metal chelating activities or singlet oxygen quenching. Because of antioxidant compound present in fruits and vegetables, the increased amount can minimize the risk of chronic degenerative diseases such as cardiovascular diseases, cancers and others. Methods like DPPH, FRAP and ORAC are used to determine the antioxidant activity in vitro because the total antioxidant capacity cannot be determined precisely by any single procedure due to the variety of phytochemicals present and the related chemical moiety diversity (Boffetta et al. 2010; Chu et al. 2000; Gandini et al. 2000; Perez-Jimenez et al. 2008; Prior et al. 2005; Van Duijnhoven et al. 2009).

Leek has abundant antioxidants. The associated advantageous effects have been attributed mainly for phenolics, ACSOs, ascorbic acid, carotenoids and tocopherols. The antioxidant capacity of the leek is in the same range as raw cabbage, raw pumpkin and celery, higher than the raw cucumber, raw tomatoes and iceberg lettuce but less than the raw broccoli, raw garlic, onion and raw spinach. The antioxidant capacity of leek with a different body part is reported in Table 16.6. Generally, the white shaft and green leaves of leek contain approximately 8 and 9 mg GAE $g^{-1}$dw and 2 and 5 mg L-ascorbic acid $^{-1}$dw antioxidants, respectively. The antioxidant

**Table 16.6** Antioxidant capacity of the different types of leek and its body parts

| Leek type/ body part | DPPH (μmol TE $g^{-1}$dw) | ORAC (μmol TE 100 $g^{-1}$dw) | FRAP (μmol $Fe_2SO_4$ $g^{-1}$dw) | References |
|---|---|---|---|---|
| Leek | Nd | 569 | Nd | USDA ( 2010) |
| | Nd | 490 | Nd | Ninfali et al. (2005) |
| Leeks white shaft | 2–11 | 379–1242 | 3–18 | Bernaert et al. (2012a) |
| Leeks green leaves | 5–14 | 1150–1904 | 14–37 | |
| GHG-L leaves | 17.65 | Nd | Nd | Najda et al. (2016) |
| GHG-L bulb | 81.14 | Nd | Nd | |

activity of leek is dependent on phenolics and ascorbic acid. White shaft of the leek has low AA content as compared to green leaves, hence white shaft showing lower antioxidant activity than green leaves in terms of the FRAP and ORAC. Green leek leaves usually have more antioxidant capacity than those of the white stem, but green leaves of leek mostly not used are removed during harvesting and processing, and the lactic acid fermentation of leek can provide an alternative to the effective utilization of the green leaf portion (Bernaert et al. 2012a; Huxley and Neil 2003; Seabra et al. 2006; USDA 2010;Wouters et al. 2013).

The antioxidant activity of methanolic extract of wild leek is assessed by DPPH and ferric reducing power assays, and its $EC_{50}$ values range between 15.12 and 0.70 $mgmL^{-1}$ of a sample of methanolic extract, respectively. The $IC_{50}$ value for DPPH inhibition of leek is 4.49 mg $ml^{-1}$, which is more than shallot and less than chive, garlic, Chinese chive and onion (García-Herrera et al. 2014; Mnayer et al. 2014).

### 16.3.2 Antimicrobial Activity

*Allium* species are characterized by their rich content in volatile allicin, other OSC, flavonoids and saponin that are responsible for the antibacterial, antifungal and antiviral activities. As compared with other OSC, allicin has strong antimicrobial action against a varied range of microbes. Allicin instantly entered through artificial and normal phospholipid membranes. Regarding the antibiotic effectiveness against gram-positive and gram-negative bacteria, authentic allicin had approximately 1–2% of the effectiveness of streptomycin (vs *S. aureus*), 8% of vancomycin (vs *S. aureus*), and 0.2% of colistin (vs *E. coli*). The oxygen in the structure (-S (=O)-S-) of allicin helps to release the S-allyl moiety, which has antimicrobial activity (Cushnie and Lamb 2005; Fujisawa et al. 2009; Miron et al. 2000; Mnayer et al. 2014; Putnik et al. 2019).

Leek essential oil (EO) contains verity of OSCs such as dipropyl disulphide (DPDS), dipropyl trisulphide and dipropyl tetrasulphide. The allyl group of OSC is accountable for the antimicrobial activity. The DADS, PTSO and dipropyl sulphide are recognized as toxicologically harmless for ordinary human consumption and food processing. Sulphides and thiosulphinates are antimicrobial against *Helicobacter pylori* and *Escherichia coli*. The antimicrobial activity of leek EO has in the order of most resistant to the most sensitive action on strains of *Pseudomonas aeruginosa* > *Escherichia coli* > *Bacillus cereus* > *Staphylococcus aureus* > *Bacillus subtilis* > *Candida albicans* > *Streptococcus pyogenes* (Behbahani and Fooladi 2018; Casella et al. 2013; Llana-Ruiz-Cabello et al. 2015a, b; Mellado-García et al. 2017; Seo et al. 2001). Antimicrobial activity of leek essential oil is mainly attributed to propyl derivatives (mainly to dipropyl trisulphide); it demonstrated antimicrobial activity against *Staphylococcus aureus*. Compound N-feruloyl tyramine and N-caffeoyl tyramine showed antifungal activity against *Botrytis cinerea* at the lowest concentration, while both *Penicillium italicum* and *Aspergillus niger* are inhibited only by N-caffeoyl tyramine at lowest doses. Cinnamic acid derivatives based on thymol and carvacrol show the antimicrobial activity by inhibiting the ergosterol synthesis in bacterial cells and destroying the membrane integrity. However, ferulic and caffeic acids are the most lethal against the microbes (Ahmad et al. 2011; Barile et al. 2007; Lanzotti et al. 2012; Mnayer et al. 2014; Puupponen-Pimiä et al. 2001; Sadeghi et al. 2013a, b).

## 16.4 Health Benefits of Leek

Leek is proven to provide many health benefits such as antiosteoporotic, antidiabetic, hypoglycemic, hypolipidaemic, antihypercholesterolemic, platelet aggregation inhibitory, free radical scavenging, anticarcinogenic, hepatoprotective, spasmolytic, gastroprotective, anti-inflammatory and immunomodulating activities (Dey and Khaled 2015; Lanzotti 2006; Lim 2015).

### 16.4.1 Immunomodulatory Activity

Leek is a rich source of water-extractable pectic polysaccharides having high molecular weight and high galacturonic and glucuronic acid and galactose content and having good immunomodulatory activity. Its immunomodulating effect is due to the presence of (1 → 3,6)-β-galactan side chains and of glucuronic acid of pectic polysaccharides. The water-extractable pectic polysaccharides have the potential to increase the activity of peritoneal macrophages and killing activity against *Salmonella enteritidis*. Pectic oligosaccharides hinder bacterial toxin receptor binding and attachment of bacterial pathogens to gut epithelial cells. Steroidal saponin isolated from leek bulbs showed immunological adjuvant activity on the cellular immune response against ovalbumin antigen and haemolytic activity in the in vitro assays. Pre- and post-topical treatment of leek volatile oil is effective against trichothecene toxin-induced epidermal injury in the mouse footpad rich in epidermal Langerhans cells. Langerhans cells show a critical role in cutaneous immunological responses (Adão et al. 2012; Ganan et al. 2010; Kratchanova et al. 2010; Nguansangiam et al. 2003; Paulsen and Barsett 2005; Rhoades et al. 2008).

### 16.4.2 Anticarcinogenic Activity

Epidemiological studies and meta-analysis indicated that the high levels of *Allium* vegetables in the diet decrease the risk of cancer, mainly cancers of the gastrointestinal tract. The OSC has been reported to prevent the growth of many types of tumours. The allyl derivatives of OSC from *Allium* are inhibiting carcinogen formation in the forestomach, oesophagus, colon, mammary glands, and lungs. This may be due to the inhibition of carcinogenic nitrosamines and heterocyclic amines which exist in the foods. Diallyl mono-, di- and tri-sulphides obtained from *Allium* are responsible to introduce apoptosis in malignant tumour cells (Chope et al. 2011; Goncharov et al. 2016; Nicastro et al. 2015; Ramirez et al. 2017; Zhou et al. 2011).

Polyphenolic compounds, such as quercetin, kaempferol and isorhamnetin, are the three main flavonoid aglycones and have aninflammatory effect on activated macrophages. Flavonoids are thought to have the strong anticarcinogenic effect that prevents cancer cell development and angiogenesis encouraging cancer cell apoptosis. The flavonoid kaempferol is protecting normal body cell functioning, neutralizing the toxic characteristics of 7-beta-hydroxycholesterol in muscle cells and avoiding programmed death in healthy cells. Besides, quercetin and kaempferol show chemopreventive effect in brain tumours and synergistically suppress cell spread in human gut cancer lines (Ackland et al. 2005; Hamalainen et al. 2007; Kim et al. 2008; Labbé et al. 2009; Ruiz et al. 2006; Sengupta et al. 2004).

Sapogenin isolated from *Allium porrum*, 12-keto-porrigenin, 2,3-seco-porrigenin, agigenin and porrigenins A, B and C, displayed cytotoxicity and high antiproliferative action on four tumour cell lines WEHI 164 (murine fibrosarcoma), J-774 (murine monocyte/macrophage), IGR-1 (human melanoma) and P-388 (murine leukaemia) cell lines in vitro. Sapogenin, namely, porrigenin C, showed a considerable antiproliferative activity on four tumour cell lines in vitro. Steroidal saponins from leek bulb, i.e. diosgenin and a spirostanol saponin derivative, showed considerable cytostatic action on human promyelocytic leukaemia HL-60 cells with $IC_{50}$ values of 2.1 and 3.2 ug/mL, respectively. Fructooligosaccharides also help in the inhibition of tumour growth and reduce the risk of cancer. Elephant garlic extracts depressed osteosarcoma cell (U2OS) viability and proliferation and affected their morphology. It does not only hinder cancer cells directly via antiproliferation but also reduces the cancer cells by delaying the metastasis process by 66.7%. It prevents the evolution from G1 phase to S phase (Irkin and Korukluoglu 2009; Huang and Ren 2013; Ly et al. 2005; Magra et al. 2006).

### 16.4.3 Prevention of Cardiovascular Diseases

*Allium* vegetable eating has substantial effects on dropping blood pressure, inhibition of atherosclerosis, decreasing serum cholesterol, triglycerides, platelet aggregation, and enhancing fibrinolytic activity. Rabbits fed with *Allium porrum L.* extract showed that plasma total cholesterol and LDL decreased significantly concerning the hypercholesterolemic group of rabbits. Polyphenolic compounds reduce vascularization and stimulate vasodilation. Kaempferol acts as a thromboxane receptor antagonist and acted as an active agent in the inhibition of atherosclerosis and acute platelet aggregation ($IC_{50}$ 20 mM) and reduces the risk of coronary heart disease (Bayan et al. 2014; Fattorusso et al. 2001; Haminiuk et al. 2012; Lin et al. 2007;Movahedian et al. 2006; Supakul et al. 2014).

### 16.4.4 Anti-inflammatory Effect

Inflammation leads to the release of histamine, bradykinin and prostaglandins (PGs). Production of pro-inflammatory cytokines during inflammation progression induced by phagocytic cells stimulates cellular activities via enhancing PGs and ROS and RNS production, and they are responsible for the development of cardiovascular and neurodegenerative disorders, such as Alzheimer's disease, atherosclerosis, cataracts, inflammation, and cancer. Organosulphur compounds such as allicin are helped in the inhibition of inflammatory processes. The anti-inflammatory activity of allicin is associated with the prevention of secretion of TNF-α-initiated pro-inflammatory cytokines from digestive epithelial cells. OSC can control the production of the Th cytokines and encouraged immune response by hindering signalling pathways and decreasing the production of inflammatory lipopolysaccharide. A bioactive compound like allyl methyl disulphide positively suppressed IL-8/IP-10 development by the TNF-α in intestinal cells. Allyl methyl disulfide also acted as a suppressor of the IL-8 mRNA in HT-29 cells and causes IκBα degradation and NF-κB p65 translocation. Leek is a rich source of PUFA, predominantly linoleic acid. The high linoleic acid composition inhibits the activity of pro-inflammatory cytokines like IL-1β, IL-6, IL-13, and TNF-α. Also, some newly isolated steroidal saponins from leek show anti-inflammatory and haemolytic effects and antiulcerogenic activities (Adão et al. 2011; Khayyal et al. 2014; Liao et al. 2012; Pan et al. 2015; Zhang et al. 2015).

### 16.4.5 Antidiabetic Property

Polyphenolic and OSC compounds and other antioxidants of *Allium* vegetables are reported to responsibly improve insulin secretion. Polyphenolic compounds help in control as well as reduction of blood glucose level by inhibiting α-amylase and α-glucosidase enzyme, shielding β-cell from glucotoxicity, triggering 5-adenosine monophosphate-activated protein kinase (AMPK), enhancing insulin-dependent glucose uptake or acting as antioxidative and anti-inflammatory to protect β-cell (Del Rio et al. 2010; Ferguson et al. 2004; Haminiuk et al. 2012; Lin et al. 2016; Melino et al. 2019; Silva et al. 2008).

Diallyl trisulphide, richly present in *Allium*, helps in control or reduction in the glucose. The in vivo study of induced diabetes model shows the reduction of intestinal absorption of glucose or increase of insulin secretion from residual B-cells in Langerhans islets. OSCs help in chelating hydroxyl radicals and superoxide which induces diabetic interfering function of alloxan, and chelating these compounds prevents diabetes. Supplementation of hydroalcoholic and ethanolic extract of leek (*Allium ampeloprasum*) extract to diabetic rats showed hypoglycemic, hypolipidemic and antioxidative properties. Leek contains high levels of ROS scavenging compound which prevents the oxidative DNA damage and necrosis of pancreatic B-cells by chelating compounds of hydroxyl radicals and performed a vital role in sustaining the viability of pancreatic B-cells. The ethanolic extract also improved serum insulin in diabetic mice. *Allium porrum* are shown to inhibit the active transport and absorption of D-glucose throughout the rat enterocytes in the rat everted intestinal sac testing. Leek consumption helps in the reduction of blood glucose level. Leeks are rich in fructooligosaccharides and other α-galacto-oligosaccharides, i.e. raffinose and stachyose, and these α-galactosides are not converted to monosaccharides due to absence of specific degrading enzyme. They passed down to the large intestine and get hydrolysed by microbiological enzymes and metabolized by colon microflora (Belemkar et al. 2013; Liu et al. 2005; Montezano et al. 2015; Rahimi-Madiseh et al. 2017; Roghani and Aghaie 2007; Selvan et al. 2008).

### 16.4.6 Other Health Benefits

The powder obtained from jumbo leek (*Allium ampeloprasum*) bulb showed the hepatoprotective activity. It decreases the initiation of hepatocyte necrosis in D-galactosamine hydrochloride (GalN)-induced acute fulminant hepatitis and forbids the incidence of ethanol-dependant chronic liver disorders in rats by stopping the absorption of alcohol from the stomach (Uchida et al. 2009).

*Allium porrum* has a significant protective effect against osteoporosis. Oral feeding of leek extract leads to restore bone mineral density in osteoporosis rats. It also decreases the ethanol-dependant elevation of alkaline phosphatase and malondialdehyde levels in serum (El-Shenawy et al. 2013).

*Allium ampeloprasum* improves reproductive functions in male rat due to its antioxidant and androgenic activities. It has a promising effect in enhancing healthy sperm parameters. Oral feeding of *Allium ampeloprasum* aids to improve male fertility and secretion of testosterone and gonadotropin levels in normal rats. *Allium ampeloprasum* extract increases the mass of testes, seminal vesicles and prostate glands, improves sperm superiority and quantity, and improved testosterone, luteinizing hormone and follicle-stimulating hormone levels in serum of testicular toxicity-tempted male rats and helps in curing sexual impotence (Jaffat et al. 2014; Morakino et al. 2008). Leek leaves ointment helps in the reduction of bleeding, anal discomfort, excretion discomfort and anal burning of all haemorrhoid patients (Mosavat et al. 2015).

## 16.5 Effect of Processing on Bioactive Compounds

Vegetables are generally treated before consumption or storage (blanching, canning and fermentation), which enhances the flavour and digestibility of foods. Before eating the *Allium* are typically processed such as blanching, boiling, steaming or stewing. Leek is the main ingredient of salads, soups, sauces, oven dishes, stewed, etc. Thermal processing tends to reduce the ACSO, polyphenol, ascorbic acid, tocopherol and carotenoid contents and also impact the antioxidant activity (Gabrić et al. 2018; Granato et al. 2018). The degradation of antioxidants and BACs during processing is subjected to its sensitivity, modification, time of exposure to processing technique and type of processing technique. Antioxidant activity of *Allium* is reduced due to heat-induced decay of some polyphenolic and OSC compounds (Wangcharoen and Morasuk 2009).

The food processing techniques like steaming, frying and microwaving are responsible for enhancing the ACSO content, while blanching had the reverse effect, maybe due to γ-glutamyl peptidase and oxidase catalysis. The synthesis of OSC in *Allium* is avoided by inactivating allinase enzymes. The ideal temperature for allinase action is 37.5 ± 5 °C, but allinase is completely inactivated by raising the temperature and time of holding (e.g. 60 °C for 105 min), while for reduction of 50% of its activity, there is a need to expose it at the same temperature for 15 min (Chen et al. 2017; Kim et al. 2016; Poojary et al. 2017; Rose et al. 2005; Shen et al. 2002).

In general, food processing steps such as fermentation, tampering, cutting and cooking (blanching, boiling and steaming) prolonged shelf-life of fresh vegetables, develops typical sensory properties and enhanced nutritional properties of the end product. Processing such as fermentation, blanching and steaming of leek results in an increase in antioxidant activity and no effect on the total phenolics, while boiling harms antioxidants and the total phenolic content. ACSO content of leeks such as methiin and isoalliin decreases due to fermentation, tampering and thermal processing like boiling and steaming, but blanching results in an increase in ACSOs, and it is found that methiin is less susceptible to heat treatment than isoalliin. Fermentation causes the enhancement of endogenous polyphenolic compounds like ferulic acid, astragalin, luteolin and naringenin, but sinapinic acid degraded after fermentation of the green leaves. It also encouraged the production of polyphenolic compounds that are not naturally occurring in the fresh leek, and these compounds are hydroferulic acid quercetin-3-O-rutinoside, quercetin-3-O-arabinoside, naringenin and dihydroquercetin (Bernaert et al. 2013a, b; Gorny 2006; Josephsen and Jespersen 2004; Hutkins 2006; Van Boekel et al. 2010; Wouters et al. 2013).

Frozen storage of leek has some effect on aroma compounds, lipoxygenase activity, carbohydrate content, antioxidant, total phenolics and ACSOs. The aroma components of leek slices undertake a notable change throughout 12 months of freezing as compared to fresh-cut leeks. OSCs such as dipropyl disulphide vary from 0.197 to 0.0409 $mgL^{-1}$ and propyl (E)-propenyl disulphide from 0.0437 to 0.00452 $mg^{-1}$. During the end of the storage, aroma profile of leek is characterized by several saturated and unsaturated aldehydes, like hexanal (1.53 to 3.63 $mgL^{-1}$), (E,E)-2,4-nonadienal (0.000 to 0.0647 $mgL^{-1}$) and (E,E)-2,4-decadienal (0.129 to 0.594 $mgL^{-1}$). The action of lipoxygenase enzyme decreases throughout the freezing period, and decrease is ~25% of the original activity of fresh leek. The carbohydrate content of leek tends to increase during 150 days of refrigerated storage period. Among studied carbohydrates degradation increases throughout storage and is responsible for increasing glucose from 4.4 to 16.2 g/100 g of DM, fructose from 4.7 to 23.8 g/100 g of DM and saccharose from 5.1 to 18.7 g/100 g of DM, and it depends on the cultivar and the storage duration. A slight increase in kestose, nystose and raffinose content is found later on the period of storage, and it varied from 0.3 to 0.9, 0.5 to 1.8 and 0.8 to 1.8 g/100 g of DM, respectively, while stachyose composition remained at a constant level during the storage period. Antioxidant activity and phenolic compound of green leaves and white shaft of leek are very lowly influenced by refrigerated storage, but significant increase in isoalliin is observed in the white shaft during refrigerated storage (Bernaert et al. 2013b; Bernaert et al. 2014; Grzelak-Biaszczyk et al. 2011; Nielsen et al. 2004).

## 16.6 Uses of Leek in the Food Industry/Processing

The leaves and white blanched stems are generally cooked, and in the cooking process, the strong flavour of leeks frequently vanishes during boiling and remains a very mild, pleasant taste to the product. These are also chopped into tiny slices and added to salads which give a slight onion flavour along with a pleasant sweetness. The dense leaf bases and slightly mature bulb are consumed with or without attached leaves. The green leaves are palatable and have a strong odour and powerful taste. They are generally used for flavouring in salads and dishes. These are used mainly for flavouring soups and stews in place of onions as a favourite leek soup dish for many gardeners. Leek has also been used extensively in the cuisines of Wales as a symbolism for the country (Anonymous 2005).

## 16.7 Conclusion

Leek is famous worldwide and consumed mostly as a vegetable, a salad and in soups. Leek has higher or same range antioxidant activity compared to other *Allium*, and it is attributed to polyphenolics, ACSOs, saponins, ascorbic acid, carotenoids and tocopherols. In leek variety of polyphenolic compounds are present, among them kaempferol 3-O-glucoside, quercetin 3-O-galactoside and ferulic acid which are present in higher quantity. Flavonoid glycosides of the leek are mono-hexose, dihexose and coumaroyl, feruloyl and caffeoyl acylated di-hexose derivatives of kaempferol. Saponins such as steroidal, spirostane, furostane, cholestane and sapogenin are present in leek, but spirostane-based saponins exhibited higher antimicrobial activity. Water-extractable pectic polysaccharides of the leek are high ($1 \rightarrow 4$)-linked glucuronic acid, galactose and rhamnose which show immunomodulatory activity. It has been found that the processing such as fermentation, steaming, blanching and refrigerated storage appeared to be accountable for better retaining of the BACs present in leek. These processes are responsible for enhancing the antioxidant activity without affecting total phenolics, while only blanching enhances the ACSOs. Leek is considered as folk medicine since ancient times. Bioactive compounds of the leek are believed to be responsible for the health-promoting properties such as antiosteoporotic, antidiabetic, hypoglycemic, hypolipidaemic, antihypercholesterolemic, platelet aggregation inhibitory, free radical scavenging, anticarcinogenic, hepatoprotective, spasmolytic, gastroprotective, antimicrobial, anti-inflammatory and immunomodulating activities.

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# Cucumber (*Cucumis sativus* L.) 17

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**Abstract**

Cucumber (*Cucumis sativus* L.) is a member of the important vegetables which belongs to the family Cucurbitaceae like gourds, melon, pumpkins, and squash. It is widely used as medicine in traditional Indian medical practices and very much liked as vegetable. Cucumber fruit consists more than ninety percentage of water, offers superior hydration, and is very low in calories as a food. Its flavor and texture have made it essential as a fresh addition to salads and in processed forms such as pickles and relishes. It exhibits various medicinal properties like antimicrobial activity, glycemic lowering ability, antioxidant ability, etc., and is traditionally used in various treatments. It is believed that its regular intake or application on skin helps in reducing the ageing effect, boosting metabolism, and improving immunity. The present book chapter provides comprehensive information on its history, production, and botanical description; the antioxidant properties of whole cucumber vegetable, characterization of the chemical compound responsible for its antioxidant proprieties, and its health benefits are also discussed.

**Keywords**

Cucumber · Antimicrobial activity · Antioxidants · Immunity · Health benefits

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## 17.1 Introduction

### 17.1.1 History

Cucumber (*Cucumis sativus* L.), also termed as kheera, is the fourth most-grown vegetable worldwide and is an associate of Cucurbitaceae family. The most popular and grown varieties of cucumber have originated from Europe and America, the Himalayas, the western part of India, and China (Mukherjee et al. 2013). Indian native cucumber is found wildly cultivated in the Himalayan region of Sikkim to Kumaun and is grown in almost every region of the nation with different language names such as cucumber (English), trapusha (Sanskrit), shasha (Bangla), kheera (Hindi), and vellarikka (Tamil) (Kirkbride 1993).

### 17.1.2 Production (India, World)

Worldwide production of cucumber is about 75,21,9440 tons with a cultivation area of 1,984,518 ha. Out of this India contributes 195,768 tons in production with 31,150 ha area of cultivation in 2018 (FAOSTAT 2018).

### 17.1.3 Botanical Description

Cucumber (*Cucumis sativus* L.) is an annual trailing plant with an average height of 2 meters. It is the most-grown plant among those of Cucurbitaceae family. This plant is characterized by its grounded roots and stem grows up on supporting frames, wrapping through hairline, spiraling tendrils. The plant is characterized by large-sized leaves that tend to form a canopy-like structure on fruits. Fruits of cucumber vary in size and generally have a length up to 60 cm long with an average diameter of 10 cm having roughly cylindrical shape with elongated tapered ends. Cucumber is classified as a fruit as its dicotyledonous and covered seed develops from flower (Mukherjee et al. 2013). Generally, it is consumed as a fresh food at pre-ripening stage. Consumers judge its quality characteristics based on freshness of horticulture products on their appearance. Cucumber skin is generally green in color having whitish shade on lower part. The color of cucumber skin may vary with its maturity index. Chlorophyll degradation is mainly associated with change in color of cucumber (Beaulieu 2011; Oms-Oliu et al. 2010).

The cucumber is regularly used as salads for its juiciness with crispy texture. However, nutritional value of cucumber is very low due to presence of high amount of water. Generally, cucumber fruit contains more than 90% water and extensively consumed as raw salads or as a cooked vegetable and sometimes in the form of pickle (Sotiroudis et al. 2010).

### 17.1.4 Proximate Composition

Being low calorific and good source of soluble dietary fiber, cucumber is ideal food for hydration and obesity management. It contains around 2.8% carbohydrates, 0.4% proteins, 0.1% fat, and 0.3 % minerals despite having 96.4% moisture (Table 17.1). Among minerals calcium, phosphorus, and iron are major contributors. Cucumber seeds are rich in protein (33.8%) and fat (45.2%) along with significant amount of carbohydrates and crude fiber contents of 10.3% and 2.0%, respectively. The crude fiber part of cucumber seed is mainly composed of indigestible materials, which prevent the constipation by increasing bowel movement. Cucumber seeds also contain significant amount of minerals having mainly calcium (2.0%), magnesium (8.5%), sodium (79.4 ppm), manganese (66.3 ppm), and iron (21.4 ppm) with trace amount of potassium (5.1%), copper (3.3 ppm), and zinc (11.7 ppm) (Abiodun and Adeleke 2010). Minerals perform a vital role in improving the digestion along with hemoglobin, teeth, and bone formation. Various factors may influence the mineral composition such as climate, cultural practices, adopted species, and type of soil and water used during cultivation (Steven et al. 1985). High potassium content (50–80mg/100g) of cucumber fruit performs a vital role in maintaining the proper blood pressure (Kashif et al. 2008). Fresh leaves and immature stems of cucumber are widely used for cooking as a pot herb (Usher 1974).

Cucumber seeds are also a good source of oil which has a nutty flavor. Small size and outer covering of fibrous coat on seeds make it difficult to extract oil from its seeds. Clear seed oil is light yellowish in appearance with a specific gravity of 0.9130. The acid value of cucumber seed oil is 0.22 with the saponification value of 1930. It also contains some amount of soluble fatty acid such as butyric acid and trace amount of unsaponification matter (0.91%). Oil has different fatty acid with predominance presence of linoleic and oleic acids. Other fatty acids such as palmitic and stearic acid are also found in seed oil (Kapoor 1990).

Cucumber contains various saturated as well as unsaturated fatty acids such as lauric, lignoceric, linoleic, myristic, nervonic, oleic, palmitic, stearic, tricosanoic, and tricosenoic acids and their amount is increased when coated into oil spices (Zhou and Mcfeeters 1998). Cucumber seed contains more than 53.7% oil and had saponification value of 231 mg KOH/g with an acid value of 3.7 mg KOH/g. Cucumber

**Table 17.1** Nutritional profile of cucumber (*Cucumis sativus* L.) whole fruit and fruit seeds

| Nutritional profile | Whole fruit | Seeds |
|---|---|---|
| Protein | 0.4% | 33.85% |
| Carbohydrates | 2.8% | 10.3% |
| Fats | 0.1% | 45.2% |
| Calcium | 0.01% | 2.0% |
| Phosphorus | 0.03% | – |
| Iron | 1.5mg/100g | 21.4ppm |
| Vitamin C | 7mg/100g | – |
| Vitamin B | 30IU/100g | – |

Source: Abiodun and Adeleke (2010)

seed oil is composed of mainly four fatty acids: linoleic acid (61.6%), oleic acid (15.7%), stearic acid (11.1%), and palmitic acid (10.7%). The chemical behavior of the cucumber seed oil is comparable to other commercial oils like cottonseed, corn, sunflower, and sesame seed oils, indicating its possible applications as table and cooking oil resulting in increased HDL and reduced LDL levels and serum cholesterol; thus it could help prevent cardiovascular diseases (Fokou et al. 2009).

## 17.2 Antioxidant Activity

### 17.2.1 Cucumber Whole Fruit

Cucumber is reported to have a significant amount of polyphenolic compounds (Melo et al. 2006). Various nonnutritive and bioactive compounds also termed as phytochemicals are found in cucumber, such as tannins, alkaloids, steroids, flavonoids, phlobatannins, and saponins (Sheetal and Jamuna 2009). Sood et al. (2012) reported the presence of various bioactive compounds in cucumber such as phytosterols, tannins, terpenoids, saponins, cardiac glycosides, and resins. Cucumber yellow extract is reported to have a significant amount of antioxidant compounds. Yellow cucumbers consumed as salad provide humans these potential antioxidants. Three cucumber verities were found to have a significant amount of antioxidants as observed in in vitro studies. These activities are probably due to occurrence of numerous biological active compounds in cucumbers like polyphenols, tannins, lycopene, and flavonoids. Various diseases are caused due to presence of free radicals in our body. Various assays such as DPPH reduction test, trolox equivalent antioxidant capacity, ferric reducing antioxidant power, and radical-trapping antioxidant activity confirmed the presence of potential bioactive compounds in cucumbers (Miller et al. 2000; Pellegrini et al. 2003; Stratil et al. 2006). Antioxidant activity of whole cucumber fruit in ethanolic and water extract was 34.3% and 28%, respectively. Total phenolic in whole cucumber fruit was 48mg/100g (Kaur and Kapoor 2002).

### 17.2.2 Cucumber Seed

The cucumber seed extract for different solvent extractions (methanol, chloroform, and ethyl acetate) showed good antioxidant activity. Methanolic extracts of cucumber seeds reported for higher antioxidant potential (Gill et al. 2009).

### 17.2.3 Cucumber Juice

Antioxidant, anti-elastase, and anti-hyaluronidase effect of lyophilized juice of cucumber fruit exhibited DPPH free radical and superoxide radical scavenging activity. It significantly reduced the enzyme activity of hyaluronidase and elastase enzyme. This can be further used in cosmetic products due to its enzyme inhibition and potent-free radical entrapping activity (Nema et al. 2011).

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

The antioxidant, anticholinesterase, and antimonoamine oxidase properties of cucumber and cabbage extracts have been reported. Furthermore, cucumber extract is also found to have significant antioxidant properties and also inhibited the lipid peroxidation in brain tissue. Cucumber exhibited high antioxidant potential as well as enzyme-inhibiting properties linked to neurodegenerative diseases as compared to cabbage extract. Among both extracts, cucumber extract showed significantly higher phenolic compounds such as quercetin, gallic acid, and caffeic acid. Such finding indicates the potential importance of cucumber in the Alzheimer's management (Oboh et al. 2007).

Cucumber contains a compound known as cucurbitacins which have potential cancer-inhibiting properties and cytotoxicity. Apart from this, cucurbitacins also have various in vitro and even in vivo medicinal effects and found their application as antifertility, purgative, and anti-inflammatory agent (Guha and Sen 1975). Fruits of cucumber plant are widely used as strong anti-wrinkle agent in a number of cosmetic products. Cucumber fruit showed DPPH free radical activity and superoxide radical scavenging activity, which supported cucumber with strong anti-wrinkle activity in a number of cosmetic products (Nema et al. 2011). Chandrasekar et al. (1989) studied the cucumber plant of Indian origin for its blood sugar-lowering potential and found that a dose of 250 mg/kg is effective in this. Cucumber seeds are widely used for the treatment of intermittent fevers and burning sensation (Warrier 1994).

## 17.4 Health Benefits

Cucumbers are the most multipurpose fruit which is widely used as mood stabilizer internally as well as externally for stress management. Early research shows that it possesses a diverse range of phytochemical compounds that may provide protecting nature against cancer and cardiovascular disease (Fig. 17.1). Phytochemicals from cucumber have a positive effect of cancer drug and found to enhance their activity. Regular intake of cucumber or its external application on skin is associated with antiaging effect, metabolism regulation, blood glucose regulation, and immunity enhancement. It was reported that cucumber has various medicinal properties like lipid-lowering potentials, antioxidant activity, antiaging, antidiabetic, and antimicrobial activity. Cucumber seeds are very helpful in the treatment of various disorders like constipation, intermittent fevers, and burning sensation (Warrier 1994). The results suggested by Gill et al. (2009) proved that the methanolic seed extract of

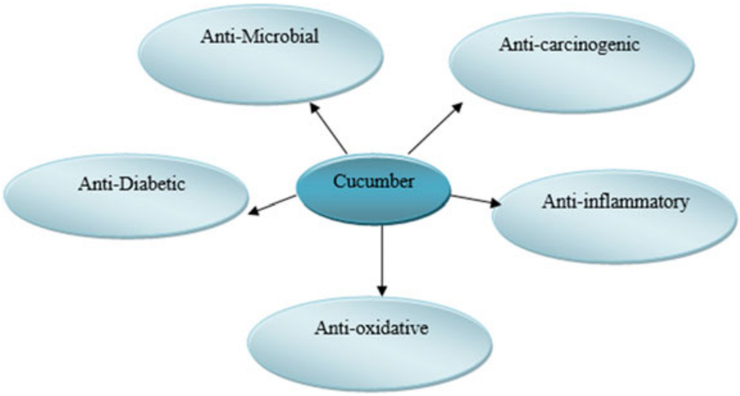


**Fig 17.1** Health benefits of cucumber (*Cucumis sativus* L.)

cucumber possessed strong antiulcer potential. Its high cellulosic content makes it indigestible for several people (Chiej 1984). Fresh fruit has found its internal application in the heat rash treatment and mottled skin while widely used for the medicinal purpose for burns and sores externally. It is also used as cosmetic products in skin softening creams (Duke and Ayensu 1985). Cucumber seeds have diuretic, cooling, and vermifuge effect. About 25–50g fine powder prepared from grinding the seeds along with seed coat is considered a standard dose for the treatment of vermifuge. This treatment requires a follow-up step of purgative expelling of worms from the body (Grieve 1998).

Cucumber fruit finds a potential application in the form of skin cleansing agent in various cosmetic formulations used for skin whitening and softening. Besides the fruit, cucumber juice is also used in a lot of cosmetic products (Grieve 1998; Chiej 1984). Solid waste generated from cucumber finds an application as cost-effective absorbent for many dye in aqueous phase such as crystal violet and rhodamine B. Cucumber solid waste with sulfuric acid acts as an environment-friendly adsorbent. Dye absorption by their combination was dependent on various factors such as dye concentration, the initial pH, and contact time. The fruit extract of cucumber is found to have various medicinal properties in mice such as antacid and carminative property (Sharma et al. 2012), analgesic, and free radical scavenging activities (Kumar et al. 2010). Significant anti-inflammatory properties in both chronic and acute inflammatory conditions have been observed in acetone extract of cucumber seed (Vetriselvan et al. 2013).

Cucumber regular consumption is associated with the healthy growth of hairs. It also plays an important role in skin problems, in swelling around eyes, and in burn cases. Skin softness is also associated with cucumber juice consumption and texture of skin softens upon regular juice uptake. Eye inflammation can significantly be reduced by placing slices of cucumber on the eyes for a period of 10 minutes. Cucumber fruit has also found a beneficial role in curing skin infection like eczema and in sun stroke (Shrivastava and Roy 2013).

## 17.5 Conclusion

Cucumbers are the most multipurpose fruit which is a widely used mood stabilizer internally as well as externally for stress management. Cucumbers are low in caloric content and a rich source of water-soluble vitamins and fibers, making it ideal for hydration and weight loss. Early research shows that it possesses a diverse range of phytochemical compounds that may protect against cancer and cardiovascular disease. Phytochemicals from cucumber have a positive effect on cancer drugs and are found to enhance their activity. Various nonnutritive and biologically active compounds, also known as phytochemicals, are found in cucumber, such as tannins, alkaloids, steroids, flavonoids, phlobatannins, and saponins. It is also known for its potential anti-wrinkle activity and predominantly used in various cosmetic goods. Volatile components of cucumber were found more effective in antibacterial and antifungal activity as compared to its extract. Regular consumption of cucumber fruits is found to be helpful in reducing the risk of many diseases. Cucumber showed strong potential against a broad spectrum of diseases, which indicates its broad spectrum of health benefits.

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# Taro (*Colocasia esculenta*) 18

Seema Sharma, Romee Jan, Ramandeep Kaur, and Charanjit S. Riar

**Abstract**

*Colocasia esculenta* is a traditional, inter-developed, and a tuberous crop harvested across the globe in tropical and subtropical areas. It correlates to the "Arecaceae" own family and is also called the "taro," the name was given to this family's tubers and roots. It is grown mainly as an affluent source of starch for the use of its palatable corms and leaves as an edible vegetable. Historically, taro was used owing to its antitumor, antimicrobial (antibacterial and antifungal), antidiabetic, antihepatotoxic, and antimelanogenic characteristics. Recent studies have documented the presence in the taro of bioactive compounds such as flavonoids, steroids, β-sitosterol, etc., which are confirmed for their health benefits. In the twenty-first century, where the consumer demands natural ingredients integrating food products, taro has various potential for use in the food industry, but after investigating its medicinal and pharmaceutical properties. This analysis will shed light on taro's bioactive and nutraceutical compounds and the possible health-promoting implications thereof.

**Keywords**

*Colocasia esculenta* · Antioxidants · Antimicrobial · Flavoniods · Health benefits

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## 18.1 Botanical and Common Names

Taro belongs to the *Colocasia* group which has monocotyledonous Colocasieae subfamily. Given the ample availability of vegetative propagation, the categorization of the Colocasia variety with a wide family is considerably mixed. The mainly domesticated taro is sorted as *Colocasia esculenta*, while the sort is also considered multiform. The taro has botanical varieties named twice: *Colocasia esculenta* (L.) *Schott var. Schott var: Esculenta* and *Colocasia esculenta* (L.) Schott Antiquorum (Purseglove 1972). In several areas, taro is known by several names, such as edode or malanga. Taro plant is known as “dmmbhe” in the Republic of South Africa, “cocoyam” in Ghana, “ndalo” in Fiji, “taro” in Tahiti, “talo” in Samoa, “gabi” in Philippines; “amateke” in Rwanda; “colcas” in Arabia; “kalo” in Hawaii, and “arbi” in India. Cultivated as a decorative herb, taro is also known as “elephant ears” (Dastidar 2009). The generic name of taro is derived from the Greek word *kolokasion*, meaning that both *Colocasia esculenta* and *Nelumbo nucifera* have an edible root component (Shekade et al. 2018).

## 18.2 Introduction

Taro is an erect tuberous perennial plant, primarily grown across tropical and subtropical areas of the globe (Kaushal et al. 2013). Taro’s botanical name is *Colocasia esculenta*, which belongs to the family of Arum (*Araceae*). This is the sixteenth most grown herb in over 60 countries worldwide. It is an abundantly grown crop in the India and is known by various titles such as eddoe, arvi, and arbi. The main reason for its production is that the edible underground corms contain 70–80% of the starch, but a leafy vegetable is also used. In India, this crop has remarkable dietary significance and has multiple uses in the form of its edible stem and corm in various culinary preparations (Nakade et al. 2013). The taro plant’s juice acts as a stimulant, rubefacient, styptic, and can be used to treat internal buboes, otalgia, adenitis, and. The taro corm juice is laxative, demulcent, and urodynamic. For health-promoting attributes such as antidiabetic, antidepressant, and antihelmintic action, the leaves have been reported (Lin and Huang 1993). The taro leaves are affluent in dietary fiber, which is advantageous for their positive function in controlling intestinal movement, enhancing the quality of dietary bulk and feces due to their water absorption capacity (Saladanha 1995).

### 18.2.1 History

Taro is one of the oldest cultivations in the world, and has a very long history; even in the Chinese books it is listed as early as 100 B.C. This is known to be native to Southeast Asia’s humid tropical regions, including India, and to neighboring countries in east China and Burma and the south to Indonesia. This is eventually transferred to Melanesia, China, Polynesia, and Hawaii; it was brought to Egypt and the eastern Mediterranean in historical times, From there to Nigeria, the Guinean coast, and the African-Caribbean coast. Data collected from the Papua New Guinea highlands shows that working on taro has been participating since ten thousand years ago, while residues of starch from Colocasia and Alocasia have also been detected on stone implements from Solomon and Buka Islands that were around 28,000 years ago (Loy et al. 1992). Historically, taro represents a predominant staple food of the people living on the Pacific Islands, particularly Hawaii, New Zealand, Papua New Guinea, and the West. It became very important for the Hawaiian people, called it "kalo" and identified with their gods and ancestors, and used for medicinal purposes (Brown and Valiere 2004; Brown et al. 2016). This plant is of special cultural significance to the Hawaiian indigenous people, the Maoli Kanaka. Such people claimed that taro had the greatest life force for all the foods and used the term "Poi," which is the Hawaiian term for the first Polynesian staple food product produced from the plant's corm portion. All (taro and Poi) serve as symbols and modes of survival, providing a ceremonial relationship for the Hawaiian people (Brown et al. 2016). It is also widely cultivated in western India and north Africa. It is grown throughout the region of Asia in southern and primal China and to a little level inside Hindustan; this crop represents also a basic diet in several drylands (Lim 2015).

### 18.2.2 Production

Taro production worldwide is estimated at 10.2 metric tons in 2017. Nigeria is the world's leading producer with 3.25 metric tons, covering about one-third of the world's production capacity data. Following this country is China in taro's output capacity, with estimates of around 1.9 metric tons. Taro is produced from around 1.72 million hectares worldwide, on an intermediate yield of 5.93 tons/ha. Based on the lowest external resource supply, the bulk of world output comes from the economically developed countries characterized by smallholder production systems (Singh et al. 2012). This crop was grown in many countries to fill the gaps in seasonal food while other crops were still grown on the fields because of their ability to yield equally under conditions where other crops could not yield due to various crop restrictions (Rashmi et al. 2018). The paddy field areas can also be used to develop the taro, where water is available in abundant or upland conditions, where rainwater or supplemented irrigation water is used for irrigation purposes (FAO 1999). It can be grown in flooded conditions among the few crops such as rice or lotus. The reason may be the presence of airspaces in the leaves leafstalk, which helps to exchange submersed gases in the surrounding area and fulfill its dissolved levels of oxygen. To achieve the optimum yield of taro, water levels should be managed so that they remain underwater at the base of the plant (FAO 1999).

### 18.2.3 Botanical Description

The taro plant is herbaceous, tuberous in nature, with a strong short caudex, flowering together, and leafing. Leaves are normally elongated arrows or heart-shaped and pointing earthward in the cluster (Prajapati et al. 2011). This plant has a few meters high erect stems and can be orange, red-black, or variegated. The adventitious and shallow root system develops ample quantities of fine starch from the corm (Reyad-ul-Ferdous et al. 2015). The broad elongated leaves that have a height of 1–2 m are called "elephant head." The dimensions of the leaves maybe 30–90 cm long & 23 inches thick, and are acquitted at the close of standing, broad, lush, 78 inches high leafstalks in crowns (Heuze et al. 2015; SafoKantaka 2004). The taro plant can grow to a height of 2 m. The plant uses reproductive rhizomes such as tubers and corms, while it also produces a bunch of 2–5 fragment inflorescences in the axil of leaves (Diwedi et al. 2016). Generally, the taro corms are cylindrical and about 30 cm in diameter around 15 cm, and can vary in scale, shape, and color.

## 18.3 Antioxidant Properties

Taro has been customarily used as a therapeutic restore herb. A large variety of bioactive mixtures from all plant portions of this species can be collected. The phytochemicals are compounds extracted from plants that have various homegrown and therapeutic properties. They show properties that are soothing, antimicrobial, antifungal, antibacterial, and antihypertensive (Mengane 2015). Diverse parts of taro plants are the main origins of components of phytochemicals that show mild to important biological activity against big organisms and diseases.

### 18.3.1 Leaves

The two pharmacologically active classes of compounds such as flavonoids and triterpenoids are found mainly in extracts of the *Colocasia* leaf. Vicenin-2, iso-vitexin, iso-vitexin 3′-O-glucoside, vitexin X′-O-glucoside, iso-orientin, orientin-7-O-glucoside, luteolin 7-O-glucoside are the flavonoids present in the concentrate of the *Colocasia leaf* (Iwashina et al. 1999). The *Colocasia* plant leaves are also rich in mineral compounds such as $CaC_2O_4$, minerals (calcium phosphorus, etc.), starch, vitamins A, B, C, and so on (Sheth 2005). The presence of anthocyanins, namely, cyanidin-3-rhamnoside, cyanidin 3-O-glucoside, and pelargonidin 3-O-beta-D-glucoside, has been demonstrated by phytochemical analyses on the *Colocasia* concentrates. These anthocyanins have cell strengthening exercises as apparent from past tests (Noda et al. 2002; Cambie and Ferguson 2003; Kowalczyk et al. 2003). Anthocyanins are predicted to be present at *Colocasia* leaves of esculenta plants are hepatoprotective of lipid peroxidative movement.

### 18.3.2 Juices

The plant leafage juice is rubefacient, excitant, astringent, and practicable for indoor hemorrhages, redness, otalgia, and nodes. The juice from the corm is softening, purgative, and painkiller. The leaves of the plant have been discovered to be hostile against the diseased person and mitigating activity for helminthic diseases (Md. Reyad-ul-Ferdous et al. 2015). *Colocasia* species have an antiquated yield and are applied throughout the world: Europe, Asia, western India, and South America. It is all being built through the muggy tropics. The plant's leaf juice is stimulant and rubefacient just like a styptic (Dnyaneshwar et al. 2018). In snake nibble, the leaf squeeze used in plant root just as food contamination as conventional medicines. A demulcent, diuretic, and anodyne corm juice (Kubde et al. 2010).

### 18.3.3 Root

Healthily, taro starches, roots, and tubers have an incredible potential to have accessible dietary fiber wellspring. Owing to the high dampness content of tubers, the energy obtained from tubers is around 33% of that of an equivalent weight of *Oryza sativa* or rice. However, large returns of roots and tubers offer more vitality per unit of land; every 24 h is equated to oat cereals all in the protein cognitive content of stems and stalks comprises less running at a dry weight premise from 1% to 2% (Food and Agriculture Organization 1990). The stem of taro holds to a greater extent than double the potato sugar substance and yields 135 kcal per 100 g and 11% rough protein on the base of juiceless weight. This comprehensive value of starch and protein is substantially more prominent than other historic crops such as yam plant, manioca, or ocarina (Food and Agriculture Organization 1999). Nevertheless, taro's protein and lipid are small, but high in sugars, vitamins, and minerals (Del Rosario and Lorenz 1999). This produces 85–87% carbohydrate on the base of juiceless weigh with a little granule size of 3–18 micrometers and various supplements, zinc, ascorbic acid, Vitamin B1, Vitamin B2, and Vitamin B3, for example, are more prominent than other ancestor crops (Jirarart et al. 2006).

## 18.4 Antioxidant Properties of Products Prepared from Taro

Because of its oxalate content, splashing, washing, or cooking of taro corms and dry leaves are prescribed before they are sustained (Pheng et al. 2008; Babayemi and Bamikole 2009). It is conceivable that taro is processed by various techniques to lessen the lethality and boost the attributes of convenience and ability. Such methods of handling include scraping, bubbling, steaming, flouring, and drying (Hang and Preston 2009). Once cooked without meat, taro retains its nutritional value, so it must be thoroughly cooked to counteract the tingling of the mouth and throat. For starters, bubbling, whitening, steaming, stewing, and singing and weight cooking, taro corms and leaves are typically devoured by people in Asia and Oceanic nations after warm narcotics. These techniques are found to be powerful in improving edibility, expanding bioavailability of supplements, and limiting the enemy of dietary components (Savage et al. 2009; Hang and Preston 2009). There was a significant reduction in the proximate composition, mineral content, phytochemical components and antinutrient contents when taro corms were made into powder and were further decreased when processed into taro noodles and cookies (Soudy et al. 2010). Both cooking time and temperature are important parameters to protect the supplements and dispense with the counter dietary variables. Cooking them again builds movement for cell reinforcement, rough fat, unrefined protein, and unrefined fiber (Soudy et al. 2010).

### 18.4.1 Flour

A noteworthy issue of taro is that while gathering, the stalks are powerless to physical harm, hence prompting a prominent crop to collect misfortunes (Onwueme 1999). Taro could be treated into flour to defeat those misfortunes. As indicated in Obadina and Hannah (2016) and Oyindamola et al. (2016), flour handling extends the period of taro usability. Root crops that are wealthy in starch are among the other elective flour wellspring. Even though wheat flour is contrasted with high starch protein, root harvesting, for example, can be considered as an elective feature for cakes and other pastry kitchen products that also have a lot of supplements and nutrients (Prajapati et al. 2011; Lim 2015).

### 18.4.2 Taro Leaf as Chicken Feed Ingredients

Shortly, it is predicted that in most developing countries there will be a considerably increase and continuing demand for protein foods for human consumption (Hang and Preston 2009). But today animal protein deficiency is one of the world's major health problems, particularly for children in developing countries, exacerbated by rapidly increasing population growth (FAO 2010). Because of a scarcity of ordinary feedstuffs, chicken items become the compass of destitute citizens, essentially grains and vegetables, which are additionally exceptionally required for direct human use. Thus, substituting cereals and expensive and less available agro-industrial by-products for unconventional sources of raw materials that are less exploited by humans is one of the solutions for reducing production costs and contributing to increased animal protein supply (Anaeto and Adighibe 2011). Also, most chicken fodders are made of oats that are deficient in certain essential amino acids resulting in synthetic amino acid supplementation, and rural farmers are therefore unable to increase the yield of meat. Thus, the incredible expense of grains and protein enhancements and vulnerability to their feasible supply squeezed the need to look for other potentially unconventional sources of feed that are generally less used for human use.

### 18.4.3 Taro Corm Flour as Complementary Food Ingredients

Factors such as category of dietary patterns determined by the elderly, acculturations, traditions, faiths, food tab uses, past knowledge of feasting designs, husbandry, unequal nutritional cognition, geographic preferences, and seasons affect the choices of complementary foods (Suhasini and Malleshi 2003). Improvement of reciprocal nourishment is guided by the high dietary benefit to enhance bosom sustaining, agreeableness, low cost and utilization of neighborhood sustenance things (Ferguson and Darmon 2007). For example, wheat, maize, rice, grain, teff, oat, millet, or sorghum, the usual correlative sustenance of porridges depends on bland staple nutrition, yet in certain areas it also forms slender roots or tubers that create gooey porridges that are hard to eat for young people (Temesgen 2013; Tessema and Belachew 2013).

## 18.5 Characterizm of the Chemical Compounds Responsible for Antioxidant Proprieties and the Pathways Involved in Biological Activities

### 18.5.1 Phytochemicals

Taro also has some substances that promote health which include antioxidants and phytochemicals that have a consequential impact on human health. They contain exceptionally good quantities of normal carotenoids which are cancer prevention agents as well as other possible medical benefits. As already mentioned, both can be converted into nutrient Vitamin A by the body; however, β-carotene affects α-carotene around double the provitamin (Nip 1997).

### 18.5.2 Phenolic Acids

Taro tubers are high in starch and include cyanidin-3-glucoside anthocyanin. Like flavonoids, it is believed that the related anthocyanins improve blood circulation by decreasing capillary fragility to improve visual perception, act as potent antioxidants, act as anti-inflammatory agents, and inhibit the growth of human cancer cells (Wagner 1985). Flour from taro corms, dried and processed, has been documented to contain simple assimilation starch, and is widely used along these lines as newborn child support (Del Rosario and Lorenz 1999). This is also used for anthocyanin analysis, in particular as regards abaxial and adaxial anthocyanin fixation.

### 18.5.3 Oxalic Acid/Oxalates

Huang and Tanudjaja (1992) estimated oxalate in corms of *Colocasia* by using chromatography of the solid anion-trade segment. The segment was created in the examination with a versatile period of 3 mM of phthalic corrosive, with its pH changed according to 3.5 using lithium hydroxide. The stream rate was 1.0 ml/min equilibrated. With a conductivity-finder, the system was fine. Both oxalates out and solvent oxalates were measured individually in 1 N HCl and separate water. The contrasts between them were insoluble oxalate substance by count. In nine taro cultivars, the complete oxalate substance was in the range of 19–87 mg/100 g of new weight and solvent oxalate substance. Insoluble oxalate substance was found to vary from 29.35% to 73.97% of the absolute oxalate substance in tested plant corms (Chai et al. 2004). Oxalates are a noteworthy limiting. The proximity of oxalates which give bitter taste or cause disturbance when eating crude or natural food is an element in taro use. The needle-like oxalate-calcium crystals, raphides, cause this acridity which may infiltrate delicate skin (Bradbury and Nixon 1998).

## 18.6 Health Benefits

### 18.6.1 Antimicrobial Activity

Aqueous accumulation of *C. esculenta* was accounted for its action against antimicrobials. The study was performed for separate microscopic organisms to be specific *Escherichia coli, Aeromonas hydrophila, Flavobacterium* sp., *Edwardsiella tarda*, *Klebsiella* sp., *Salmonella* sp., and *Vibrio alginolyticus*, *V. parahaemolyticus*, *V. cholera*, *and Pseudomonas aeruginosa.* The separate plant showed the most intense movement against *S. mutans* between all the microorganism strains selected. The *C. esculenta* demonstrated strong antimicrobial activity against certain low-fixation microscopic species and parasites (Singh et al. 2011).

### 18.6.2 Antidiabetic Activity

The ethanol concentrates on *C. esculenta*'s antidiabetic action. The antidiabetic action of the ethanol concentrate of *C. esculenta* (EECE) forgets was conveyed in rodents utilizing alloxan-initiated diabetes model. EECE (100, 200, and 400 mg/kg) and metformin (450 mg/kg) were orally controlled in diabetic rodents actuated by alloxane (120 mg/kg, i.p.) At 4 h (96 mg/dl), the beginning of blood glucose decrease was reported, with a crest at 6 h (120 mg/dl) but hostile to hyperglycemic effect decreased at 24 h. During the fourteenth day, the most significant drop in blood glucose was observed (174.34 mg/dl) at the 400 mg/kg section of the subacute test. Such findings indicated that EECE (400 mg/kg) demonstrates antihyperglycemic movement in diabetic rodents initiated with alloxane (Patel et al. 2012; Kumawat et al. 2010).

### 18.6.3 Anti-lipid Peroxidative Activity

The free radical rummaging property was accounted for in whole leaf juice *C. esculenta*. The impact of in vitro free radical rummaging was contemplated with the use of rodent liver cut models on liver cells. The liver cuts were brooded in the vicinity of the CCl4 and acetaminophen cytotoxic centralizations. The checked rises and anticipation of exhaustion of complete tissue glutathione were seen within the sight of *C. esculenta* entire leaf juice (Bhagyashree and Hussein 2011a, b).

### 18.6.4 Antimetastatic Activity

Breast malignant growth mortality stems primarily from a case of metastatic infection. The compound(s) deriving from the underlying foundations of *C. esculenta* plant can prevent metastasis in tumors, both conceivably and directly. In a preclinical model of metastatic breast disease, it displayed clear movement. Taro removes treatment with a similarly repressed mixture of prostaglandin E2 (PGE2) and downward directed cyclooxygenase 1 and 2 mRNA. Taro extricate humbly hinders the expansion of a few, but not all, cell lines of the breast and prostate disease, and it completely squares the relocation of tumor cells (Kundu et al. 2012).

### 18.6.5 Antifungal Activity

Yang et al. tested the antifungal motion of taro alongside tests of atomic cloning and recombinant efficiency articulation. CeCPI, a cysteine protease inhibitor (cystatin), was isolated from *Colocasia esculenta*, a taro corm. The test indicated that the recombinant CeCPI protein showed an unequivocal movement of the cysteine protease inhibitor. So, the analysis found a simple toxic effect of the plant on mycelium production from phytopathogenic parasites (Yang and Yeh 2005).

### 18.6.6 Anti-inflammatory Activity

The ethanolic leaves concentrate on *C. esculenta* have the movement minimizing. The study was carried out in Wistar rodents using the granuloma model caused by carrageenan instigated left rear paw edema, carrageenan-prompted pleurisy, and cotton pellet. The findings showed that when contrasted, the ethanolic extract shows vital calming action, and normal and untreated regulation (Shah et al. 2007).

## 18.7 Other Uses/Applications

### 18.7.1 Medicinal Uses

*C. Esculenta* as discussed earlier has various restorative uses. In addition, every part of the plant, viz. leaves, roots, and tubers showed numerous restorative properties. The reported properties against lipid peroxidative action, antimetastatic, antifungal, mitigating, and some more areas antimicrobial, antihepatotoxic, hostile to diabetic. Munda clan individuals generally use taro corm as a solution for body hurt. For alopecia, the juice derived from the plant's corm is used as an expectorant, stimulant, hors d'oeuvre, and astringent. The crop contains adhesive when cooked and is found to be a convincing tonic to the nervine (Soumya et al. 2014).

### 18.7.2 Pharmaceutical Applications

The gum got similarly from the tuber as starch. *C. Esculenta* plant can be used as a pioneering spread and administrator of mucoadhesive molding systems (Soumya et al. 2014). Soumya et al. (2014) successfully arranged, using metoprolol succinate as the model medication, to release and survey taro gum network tablets. As self-ruling variables, the calculation of taro gum (X1) and polyvinylpyrrolidone (PVP) K30 (X2) was chosen. As the destitute component, the time needed for 90% of the in vitro drug release was chosen. Tablets were prepared by direct weight and surveyed for various post-weight parameters such as tablet hardness, friability, weight variety, cure quality, and breakdown in vitro (Soumya et al. 2014). Another Arora et al. review paper declared the use of taro gum being created from mucoadhesive system tablets. Domperidone structure tablets as a model drug have been stuffed using a direct weight process. This study demonstrated subordinate fascination with mucoadhesive and release the retardant potential of taro gum in the enumeration of gastro retentive mucoadhesive cross-section tablets (Gurpreet et al. 2011). Chukwu and Udeala (2000) mulled over enough *C. esculenta* gum in the subtleties of paracetamol and metronidazole tablets which are incapable of being compressed. Ampleness of polysaccharide gum received from the *C. esculenta* in the case of insufficiently compressible medicines was surveyed with acacia and methylcellulose as folios. At 4% w/w, the apparent centralization of *Colocasia* gum in metronidazole tablets and 6% w/w in paracetamol tablets showed long disintegration time and postponed release profile. The clasp used for analysis yielded tablets that showed better characteristics of in vitro release (Chukwu and Udeala 2000). *C. Esculenta* polysaccharide can be used as a disintegrant in orally separating tablet arrangements. The decaying property was described as being practically indistinguishable from that of the super-disintegrants available in monetary terms.

## 18.8 Conclusion

In this analysis, we discussed the botanical definition, phytochemical, and pharmacological usage of *C. Esculenta*. For various pharmacological activities such as analgesic, anti-inflammatory, anticancer, antidiarrheal, astringent nervine tonic, and hypolipidemic activity the plant has been studied. The plant also contains various biologically active phytoconstituents, such as flavonoids, sterols, glycosides, and other micronutrients, chemically. In the medicinal and pharmaceutical areas, therefore, it must be used to its full ability. *C. esculenta* is a mainly cultivated herb, which has been used as food and medicine since ancient times.

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# Part II

# Nuts

# 19 Coconut

Mamta Thakur, Kirty Pant, and Vikas Nanda

**Abstract**

The coconut palm (*Cocos nucifera* L.) finds extensive usage in a nation's economy by providing a wide spectrum of edible products like kernel, water, oil, milk, sap sugar, etc., therefore being recognized as "tree of life". The coconut and its derived products contain significant amounts of biologically active constituents like antioxidant vitamins, phenolic compounds, and amino acids which contribute to its antioxidant properties. The coconut products exhibit plenty of biological effects following the mechanism of (i) transcription factor and gene expression activation, (ii) free radical scavenging, (iii) metal sequestration, and (iv) regulating the enzymatic activity and signal transduction, thus promoting health. The present chapter provides insight into various aspects of coconut palm covering history of origin, current coconut production scenario, botany, and different edible parts of coconut. This chapter presents the antioxidant properties of coconut products using a comprehensive approach for the first time underlining their mechanism of carrying biological effects. The health benefits of coconut products will also be highlighted in this chapter by with scientific evidence provided with the studies supported through the systematic scientific approaches.

**Keywords**

Coconut · Antioxidants · Vitamins · Phenolic compounds · Amino acids

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## 19.1 Introduction

**Botanical name**: *Cocos nucifera* L. **Common name**: Coconut

Coconut, also known as coconut palm, is one of the most valuable plants in global tropical regions, subtropical islands, and coastal ecosystems. It is botanically known as *Cocos nucifera* (family Arecaceae) where the term "cocos" is derived from a Spanish word which means "spectre or goblin" in context to the three spots above the coconut surface, while the "nucifera" is a neo-Latin term which consists of *nux* meaning nut and *ferre* meaning carry or bear. Thus, "nucifera" refers to "bearing nuts". Coconut – the world's largest cultivated palm – has supplied the shelter, food, and transportation to the human from very ancient times (Manivannan et al. 2018). It is popular as "nature's lavish gifts to man", "the tree of thousand uses", "milk bottle on the doorstep of mankind", and "tree of life" among many communities due to its diversified products which support the local economy (Bourdeix et al. 2006).

Coconut palm is different from other palms due to its greater stability and regularity for several months, years, and even decades on the basis of flowering and fruit production. Coconut is the main perennial plantation crop of smallholders which thus contributes to the rural development and exhibits the potential to mitigate the poverty in developing countries. It is a highly versatile crop which requires minimum attention. The warm conditions having an ideal annual 27 °C temperature are essential for its cultivation. However, the plant is intolerant to cold conditions and could not grow properly below 21 °C (Agyemang-Yeboah 2011). It is usually planted in the lowlands just above the sea level. The coconut tree can be as tall as 30 m having a curved but slender trunk and starts to produce fruits after 6 years. Coconut palm produces a variety of products ranging from whole fruits, husk, meat/flesh/endosperm, milk, coir, water, and mesocarp fibres to oil. The edible products like neera, toddy, and coconut sugar are also derived from coconut sap during inflorescence. In addition, the dried form of coconut, termed as copra, used for oil extraction is also an important cash crop. A variety of items are made of coconut kernels including desiccated coconut, defatted coconut, and coconut cream as well as milk powder. Among plenty of coco products, the coconut oil has been most studied attributed to its positive health effects due to its distinct fatty composition (Fife 2003; Krishna et al. 2010; Dayrit 2014). Moreover, the coconut water has recently been gaining popularity as a natural nutritional and energy drink because it is rich in micronutrients.

The intake of coconut water was recommended as a rehydration remedy for acute diarrhoea by the World Health Organization (WHO) and UN International Children's Emergency Fund (UNICEF) (UNICEF/WHO 2009). Several research works exhibited the higher amount of polyphenolic compounds in coconut testa as well as in extracted virgin coconut oil (Appaiah et al. 2014; Seneviratne et al. (2009). The coconut milk showed the highest antioxidant potential as compared to goat and cow milk (Alyaqoubi et al. 2015). Each part of coconut and its value-added products have significant phenolic and flavonoid compounds contributing to its antioxidant potential; therefore, the pharmacological effects of the plant vary with its part under study (Arivalagan et al. 2018). Generally, the constituents of coconut showed anthelmintic, antioxidant, antidiabetic, antifungal, antihypertensive, antimicrobial, antinociceptive, antiosteoporosis, anti-inflammatory, and anticancerous potential and protect the heart, kidney, and liver functions (Akinpelu et al. 2015; Lima et al. 2015).

Many research papers are available in literature reporting the biological properties of different parts of coconut; however, a comprehensive study on antioxidant properties and health benefits of all coconut parts together is scanty. Therefore, this chapter introduces the coconut palm to researchers and scientists based on its antioxidant properties. Major attention is paid to the recent studies on identifying and characterizing the chemical compounds attributing to the antioxidant properties of whole coconut fruit and its other parts. The different metabolic pathways involved in the biological activities are also highlighted. The chapter, at the end, also provides insight into positive health impact of coconut which would be explained using their distinct mechanisms.

### 19.1.1 History

Coconut palms are very historic species with the unique past of domestication initially from coastal areas. Initially, several arguments were given in support of native place of coconut as follows: Martius (1850) considered the Western Coast (which covers the Pacific Ocean) of Central America as the source of coconut emergence which was also supported by Cook (1901); then De Candolle (1886) suggested the palms' genesis in the Indian archipelago which was strengthened by several other studies (Beccari 1917; Mayuranathan 1938; Nayar 2018). Later on, the Pacific origin of this palm was explored by Purseglove (1968), whereas the extensive distribution of coconut from Africa to South America was reported by Harries (1978). Coconut tree being the utmost abundant plant existed over >30,000 islands covering the shoreline of tropical as well as subtropical seas of Old World. It was spread over the tropics mainly by the sea currents and nautical people. However, the cultivation of coconut trees started when people came to the Pacific and Indian Oceans.

The coconut trees are dominantly present in low-lying tropical atolls of the Pacific; however, the native origin of these palms is still dubious today with two contradictory thoughts. Some investigations about fossil and molecular data suggested the Southeast Asia as the origin of these palms (Arunachalam and Rajesh 2008). Another study conducted by Harries and Clement (2013) stated that coral atoll ecosystem had first coconut palm from where they dispersed due to the consistently varying form and its widespread nature resulting in the debateful geographical origin of coconut. Currently, coconut is being commercially cultivated in more than 98 countries due to its plenty of applications. Kerala – recognized as "Land of Coconuts" – is an Indian state which attained its appellation from the word "KERA" (meaning coconut tree) along with "ALAM" (meaning land/place). Coconut is part of the daily diet of Kerala people who use coconut in cooking oil, disease prevention, and hair and skincare, coir in furnishing and decoration, endocarp in milk extraction, coconut water as nutritious beverage, palm leaves and branches for building their homes, and dried coconut as a source of fuel.

### 19.1.2 Production (World and India)

Coconut is a major source of income in developing countries leading to the significant contributions in local economies of these nations. These are grown between the latitudes 20°N and 20°S of equator in seashore areas and up to an altitude of about 1200 m above the sea level, requiring the high humidity, 27–30 °C temperatures, and medium to well-aerated deep soils. In 1961, the coconut production was ranked 4th among 14 vegetable crops and accounted for approximately 25% of total oil crops. However, coconut production has been increased since the 1980s.

Currently, the coconut is produced in quantity 60.77 million tonnes covering an area of 12.30 million hectare over more than 94 countries globally, as shown in Table 19.1. In 1961, the world coconut-harvested area was 5.26 million hectares, while production was 23.84 million tonnes which has been increased to the abovementioned numbers in 2017 (Fig. 19.1). The coconut production was mainly focussed in Asia contributing to 82.8% of world's production, followed by Americas (7.9%) and Oceania (5.2%). The top five coconut-producing countries include Indonesia, the Philippines, India, Sri Lanka, and Brazil. Among these, the major three players – Indonesia, the Philippines, and India – supply more than 73% of the total world production. The Philippines occupies the largest land area under coconut cultivation (3.61 million hectares) prior to Indonesia (3.26 million hectares) and India (2.08 million hectares). On the other side, Brazil and Vietnam have maximum

**Table 19.1** Summary of the production, harvest area, and yield of coconut in leading countries of the world (2017)

| Country | 2017 | | |
|---|---|---|---|
| | Production (million tonnes) | Harvest area (million hectares) | Yield (tonnes/ hectares) |
| **World** | 60.77 | 12.30 | 4.94 |
| **Indonesia** | 18.98 | 3.26 | 5.82 |
| **Philippines** | 14.05 | 3.61 | 3.89 |
| **India** | 11.47 | 2.08 | 5.51 |
| **Sri Lanka** | 2.58 | 0.41 | 6.29 |
| **Brazil** | 2.34 | 0.22 | 10.86 |
| **Vietnam** | 1.49 | 0.15 | 10.12 |
| **Papua New Guinea** | 1.20 | 0.20 | 5.87 |
| **Mexico** | 1.16 | 0.18 | 6.31 |
| **Thailand** | 0.89 | 0.19 | 4.66 |
| **United Republic of Tanzania** | 0.56 | 0.74 | 0.75 |

Source: FAOSTAT (2019)

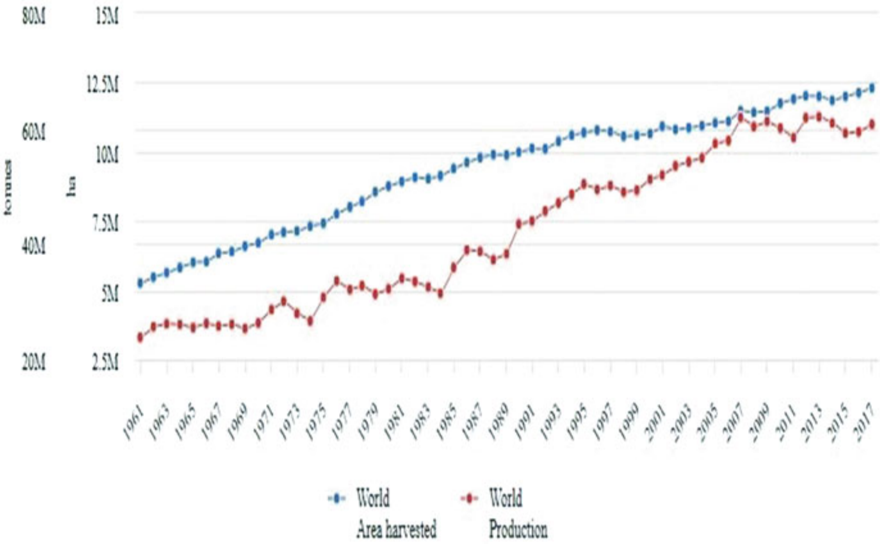



**Fig. 19.1** Trend of coconut area harvested and production in the world from 1961 to 2017. (Source: FAOSTAT (2019))

coconut yield (10.86 and 10.12 tonnes/hectares, respectively) compared to the world yield of 4.94 tonnes/hectares (FAOSTAT 2019).

In India, coconut has a great significance in national economy, generating employment, income, and export opportunities. Coconut is being used as food crop and an oilseed over 300 years in India which ranks third in the global coconut production (Table 19.1). It is grown by small and marginal land holder farmers mainly for coconut oil and copra. It is not cultivated in each state of India but limited to coastal areas. Approximately ten million people rely either directly or indirectly on coconut cultivation, processing, and other trading activities. Coconut oil is considered as the finest quality edible oil which accounts for 6% of country's vegetable oil production.

Coconut production is mainly confined to Kerala, Karnataka, Tamil Nadu, and Andhra Pradesh which collectively contributes to nearly 93% of total production in India (Table 19.2). Kerala state occupies the largest area under coconut cultivation and produces 35.52% of total production; however, the highest coconut productivity is obtained from Andhra Pradesh (14,038 nuts/hectares) followed by Tamil Nadu (13,637 nuts/hectares) and West Bengal (12,484 nuts/hectares). Coconut is also grown widely in Indian island groups like Andaman and Nicobar and Lakshadweep islands. However, the northern, central, and eastern states of India are not suitable for coconut cultivation due to their unfavourable climatic conditions (Coconut Development Board 2019).

According to the reports of Indian Ministry of Agriculture and Farmers' Welfare, the coconut accounts for Rs. 27,900 crores to the national GDP and was exported worth of Rs. 2084 crores in financial year 2016–2017. In India, the Coconut

**Table 19.2** Summary of the coconut: area harvested, production, and productivity in major coconut-growing Indian states

| S. N. | States | Harvested area (″000 hectares) | Production (million nuts) | Productivity (nuts/ hectares) |
|---|---|---|---|---|
| **1** | Kerala | 807.13 | 8452.05 | 10,472 |
| **2** | Karnataka | 518.39 | 6273.79 | 12,102 |
| **3** | Tamil Nadu | 441.49 | 6020.41 | 13,637 |
| **4** | Andhra Pradesh | 99.51 | 1396.89 | 14,038 |
| **5** | Odisha | 50.91 | 341.71 | 6712 |
| **6** | West Bengal | 30.25 | 377.65 | 12,484 |
| **7** | Maharashtra | 26.97 | 127.92 | 4743 |
| **8** | Gujarat | 24.94 | 241.16 | 9670 |
| **9** | Assam | 19.92 | 168.21 | 8444 |
| **10** | Bihar | 11.35 | 76.68 | 6756 |
| **11** | Tripura | 4.57 | 31.93 | 6987 |
| **12** | Chhattisgarh | 1.54 | 10.92 | 7091 |
| **13** | Nagaland | 1.18 | 9.44 | 8000 |
| **14** | Others | 58.57 | 269.47 | 4601 |
| | **Total** | **2096.72** | **23798.23** | **11,350** |

Source: Horticulture Division, Department of Agriculture and Cooperation, Ministry of Agriculture and Farmers' Welfare, Government of India

Development Board is the main organization which aids the farmers regarding cultivation, processing, marketing, and export of coconut and its products. India also started the export of coconut oil and desiccated coconut recently. Efforts are being carried out to cultivate coconut in Bihar because the Board found approximately 50,000 hectare area in Bihar ideal for coconut cultivation under irrigation. However, the per capita availability of coconut is very less in India (8 nuts/year) compared to the Philippines (190 nuts/year) and Indonesia (56 nuts/year) (Ministry of Agriculture and Farmers Welfare 2018).

### 19.1.3 Botanical Description

Coconut is a member of the Arecaceae family of *Cocos* genus and has a long life of nearly 100 years. It is usually diploid having 32 chromosomes and a monocotyledon, assisted by a root system having tall (>30 m) centralized trunk (Dransfield et al. 2008). The top of coconut contains rosette leaves, arranged to a five spiral frond phyllotaxis. A palm can produce maximum of 17 fronds per year under the optimum conditions which remains for nearly 3 years in the tree. After that, they are naturally shed from trunk on which the permanent ringed mark is left. There is only one growing point which leads to the stem elongation and generation of leaf, flower, and nut. The bright-green coconut leaves are pinnate, rigid, 4–6 m long, and shaped like linear-lance head. The coconut flowers have lanceolate petals, six stamens, and three

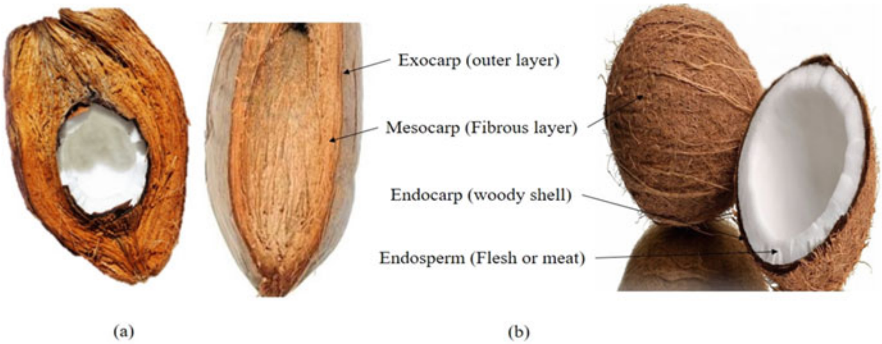



**Fig. 19.2** (**a**) Single-seeded coconut drupe and (**b**) different parts of coconut fruit

connate carpels containing one ovary which results in the continuous flowering. Mostly, the coconut is propagated by cross-pollination that can be achieved by either wind or insects. After fertilization, the fruits take 10–12 months to mature.

Botanically, the coconut is not a nut but a single-seeded drupe (Fig. 19.2a) which has varying size based on the breeding and source. Generally, the coconut fruit is oval to spherical in shape having three layers, the exocarp, mesocarp, and endocarp, as shown in Fig. 19.2b. The initial two layers – exocarp and mesocarp – contain a hard outer husk consisting of sturdy fibre. The young coconut has varying colour depending on the cultivar, but the exocarp of dried or ripe nuts are usually brown in colour. The coconut fruit weighs 1–2 kg and has a smooth brown colour epicarp and fibrous mesocarp (4–8 cm). The endosperm consists of a woody shell, present under the husk which encloses the kernel or flesh and mild sweet edible clear water, known for its nutritional properties. A layer of testa is present just inside the shell which sticks to thick endosperm in mature coconut. After removal of husk, three germination pores or eyes can be visibly noticeable on the surface of shell. These eyes are the paths through which the radicle of seed embryo emerges out on its germination. Coconut kernel is known for higher amount of minerals (iron, phosphorus, and zinc), and medium-chain saturated fats (Enig 2001).

## 19.2 Antioxidant Properties of Coconut Fruit (Juices, Husk, Shell, Meat) and Oil and Its Products (Coconut Sap, Milk, Cake, Copra, and Sap or Neera)

Humans throughout the history have used each part of coconut for different purposes. There are plenty of edible products derived from the coconut palm (Fig. 19.3), meat/flesh, coconut oil and water, husk, shell, sap, coconut milk and cake, copra, neera, etc., which offer distinct nutritional and health properties. The biological effects of coconut such as anti-inflammatory, antifungal, anti-helminthic, antitumor, antinociceptive, and antimicrobial activities are mainly attributed to its antioxidant properties, enhancing the human health (Naczk and Shahidi 2004). The


**Fig. 19.3** Different products derived from coconut palm

phenolic compounds and flavonoid compounds are found in the following parts of coconut which contribute to its antioxidant properties.

**Coconut Fruit** As discussed above, the coconut fruit consists of the exocarp, mesocarp (husk), and endocarp (shell, kernel/meat, water/juice). Several products can be derived from coconut meat such as copra, coconut oil, milk, and cake whose antioxidant properties will be discussed here as follows.

### 19.2.1 Coconut Husk

The coconut husk is a potential source of antioxidant. The dried coconut husk has been used in traditional medicines of many cultures till today. In Nigeria, the coconut husk has been added in the diabetic diet from historic times. Muritala et al. (2018) reported that the coconut husk is rich in polyphenols exhibiting the potential to scavenge free radicals. They recommended the exploration of coconut husk in nutraceutical supplements or special food formulations. Roopan (2016) stated that the phenolic content of coconut husk is responsible for its biological activities including antioxidant properties. Further, the antioxidant potential of coconut husk determined in vitro was equivalent to the chemical standards (ascorbic acid, rutin, and quercetin) used in the study (Silva et al. 2013). The phenols contain functional hydroxyl (-OH) group in their structure which interacts with the free radical and donates the hydrogen to make a more stable complex. It is believed that the characteristics of scavenging free radicals are shown better by coconut varieties which contain higher total phenolic content (TPC) (Bezerra dos Santos Oliveira et al. 2013). The yellow dwarf and hybrid variety had the highest values of TPC (501 mg GAE/g and 531 mg GAE/g dry extract, respectively), whereas DPPH (1,1-diphenyl-2-picrylhydrazyl) free radical scavenging activity was maximum in green dwarf variety followed by hybrid, yellow dwarf, and giant cultivar. Coconut husk has also revealed the potential to scavenge other radicals like hydrogen peroxide ($H_2O_2$), ABTS (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid), nitric oxide (NO), and superoxide (Lima et al. 2015). Adaramoye et al. (2016) provided the coconut husk-based chloroform extracts to cisplatin-induced rats which reported the inhibition of lipid peroxidation leading to an improved antioxidant defence system of experimental animals in addition to inhibit the lipid peroxidation.

### 19.2.2 Coconut Shell

The shelling of coconut produces two main by-products, coconut husk (as discussed above) and shell, which are easily available at cheaper price in coconut-producing countries like India. Coconut shells on a very small scale are employed in charcoal and other non-food item production but are being wasted in a great quantity, contributing to solid waste irrespective of the fact that this by-product is a valuable source of phytochemicals (Prakash et al. 2018). Usually, the shell is made up of cellulose and lignin which is alike to the chemical composition of wood (Gunasekaran et al. 2011). However, Prakash et al. (2018) reported the coconut shells (1056.32 mg GAE/L) as a source of antioxidants which have higher activity than groundnut hulls (426.35 mg GAE/L) but lower antioxidant capacity compared to cashew nut shells (3412.28 mg GAE/L). The maximum levels of polyphenols were achieved from coconut shell when extracted using microwave. This may be due to the microwave irradiation-derived cleavage of chemical bonds between lignins and polyphenolic compounds resulting in their release in extract. On the other hand, the coconut shell exhibited the potent radical scavenging activity, as determined by in vitro antioxidant assay, than cashew nut shell and groundnut hull (Prakash et al. 2018). The shell extract also showed a significant antioxidant potential comparable to standard ascorbic acid which was calculated using DPPH radical scavenging method (Singla et al. 2011). Further, research work is needed to investigate more about these unconventional sources of antioxidant to use them as natural food preservatives.

### 19.2.3 Coconut Meat and Copra

The white edible flesh of coconut, used to extract the oil, milk, and cream, is known as meat, whereas the dried form (6–8% moisture content) of meat is referred to as copra. Globally, the copra is employed to extract the distinguished lactonic odour in flavour and fragrance industries. Few studies are conducted about the antioxidant potential of copra which showed that phytochemicals like alkaloids, flavonoids, phenols, saponins, and tannins were responsible for its antioxidant and reducing power properties (Whitney and Rolfes 2008; Odenigbo and Otisi 2011). The coconut meat contained TPC varying from 5.18 to 7.17 mg GAE/100 mL, whereas the whole copra had lower total phenols (0.2 g GAE/100 g) than coconut cake (0.8 g GAE/100 g) and testa (6.3 g GAE/100 g) (Mahayothee et al. 2016; Appaiah et al. 2016). Moreover, the tocopherol content was found in the following order: cake (1.2 mg/100 g) > copra (7.5 mg/100 g) > testa (49.2 mg/100 g). In contrast, the fresh coconut meat contained polyphenols varying from 18.5 to 24.8 mg GAE/100 g (Appaiah et al. 2014, 2015) in addition to the amino acids, minerals, and tocopherols (Abdul and Zafar 2011). Meat contains the following main phenolic acids: caffeic, p-coumaric, gallic, and salicylic acids. On maturation of coconut up to 190 days, the TPC and antioxidant activity of coconut meat were increased but then reduced at 225 days after pollination (Mahayothee et al. 2016). They found higher TPC and antioxidant properties in meat compared to coconut water, calculated on wet basis. This was also supported by Leong and Shui (2002) who revealed approximately four times higher free radical (ABTS) scavenging potential of meat than water in Malaysian coconut. However, according to ABTS levels, the antioxidant potential of both coconut meat and water was categorized as "low".

### 19.2.4 Coconut Juice (Water)

The coconut juice, more commonly known as coconut water, is a refreshing and nutritious traditional drink, particularly in Southeast Asia and Latin America. The coconut water which is ready to drink has also been attracting the consumers' interest and attention globally due to its health properties (Prades et al. 2012a). It contains sugars, amino acids, minerals (boron, calcium, iodine, magnesium, manganese, molybdenum, methionine, potassium, selenium, and zinc), vitamins, and certain polyphenolic compounds mainly catechin and salicylic acid (Prades et al. 2012b; Yong et al. 2009). Micronutrients in coconut water boost the antioxidant defence system of the body. The coconut water contained TPC varying from 6.28 to 10.01 mg GAE/100 g (Mahayothee et al. 2016).

Natural coconut water exhibits the antioxidant property which however reduces sharply on thermal processing, addition of acids or alkaline substances, and fruit maturation (Leong and Shui 2002; Mantena et al. 2003). The antioxidant activity of coconut water of cultivars green dwarf, red dwarf, yellow dwarf, and yellow Malaysian was investigated by Santos et al. (2013) to compare it with commercial coconut waters and lyophilized coconut green dwarf variety water. They reported the significant antioxidant activities in all coconut water from four cultivars on the basis of minimizing DPPH (IC50 – inhibition concentration: 73 mL) and nitric oxide (IP – inhibition percent: 29.9%) and producing thiobarbituric acid (34.4%), and maximum antioxidant properties were revealed by green dwarf cultivar than others, whereas the water from green dwarf cultivar was most effective to protect against hydrogen peroxide-induced oxidative damages in cell culture.

Some studies demonstrated that when coconut water was fed (6 mL per100 g body weight) to carbon tetrachloride ($CCl_4$)-intoxicated female rats, they regained the activity of superoxide dismutase and catalase enzymes (showing antioxidant potential) and also reduced the lipid peroxidation. Further, a free form amino acid L-arginine (30 mg/dL) and ascorbic acid (15 mg/100 mL) were also found in coconut water which were also responsible for the decreased free radical generation, thus showing antioxidant activity, and reduced the oxidative degradation of lipids in rats (Das et al. 2001; Salil and Rajamohan 2001; Loki and Rajamohan 2003; Lima et al. 2015). Similarly, another work conducted by Anurag and Rajamohan (2011) revealed the improvements in mitochondria and protection against free radical (isoproterenol) generated damage from coconut water. The oxidative stress was also prevented in the labourers working in traditional gold mines who were consistently exposed to mercury (Zulaikhah et al. 2015).

### 19.2.5 Coconut Oil and Virgin Coconut Oil

Extensively used in food processing, the coconut oil is extracted using hydraulic, screw, or wedge press using two techniques, viz. dry and wet processing. The oil is widely extracted from copra using dry processing which is then refined, bleached, and deodorized (RBD). In contrast, the fresh coconut milk besides copra is employed to extract the cream, and then the cream emulsion is broken without any chemical or high temperature treatment. This process is called wet processing (Marina et al. 2009a, b). The oil thus extracted refers to virgin coconut oil (VCO) which is recognized as functional oil these days. VCO, manufactured using wet processing, therefore does not go through any kind of chemical treatments like refining, bleaching, and other secondary steps as seen in dry processing technique. Ghosh et al. (2014) recommended the mechanical method of oil extraction than Soxhlet extraction due to the lower phytochemical content in the latter.

Studies reported that VCO had approximately seven times higher TPC compared to commercial coconut oil, thereby also resulting in higher antioxidant activity (DPPH test) (Seneviratne and Sudarshana-Dissanayake 2008; Marina et al. 2009a, b). RBD processed commercial oil (dry method) may result in the destruction of phenolic compounds which decreases the antioxidant potential of oil. On the other hand, Seneviratne et al. (2009) found that the hot extraction (100–120 °C)-derived coconut oil showed higher phenolic content and antioxidant potential (DPPH and deoxyribose assay) compared to cold (10 °C)-extracted oil. This is totally opposite to the belief that cold-processed VCO retained plenty of heat-sensitive antioxidant compounds offering beneficial qualities to it. However, the coconut oil extracted under hot conditions contained higher concentration of thermally stable polyphenolic compounds; therefore, its intake would improve the antioxidant-associated health benefits in a better way. Further, the high temperature may also improve the solubility of polar polyphenolic compounds in organic coconut oil (Seneviratne et al. 2009).

Another study by Marina et al. (2008) evaluated the antioxidant potential (-β-carotene-linoleate bleaching, DPPH radical scavenging, and reducing power activity) of VCO under different extraction conditions – chilling and fermentation. In fermentation method, the coconut milk was fermented for 12 h during which the released oil would come to the surface due to gravity difference, whereas the chilling method involves the centrifugation and subsequent separation of coconut cream from milk. They reported the highest TPC in oil produced using fermentation method followed by chilling and RBD technique. This might be due to the increased incorporation of phenols into oil matrix attributed to the longer residence time of oil and phenolic compounds in the fermentation extract. But the aqueous phase might contain some residual phenolic compounds which resulted in decreased TPC during chilling processing. The fermentation-processed oil also exhibited the maximum antioxidant effect as per DPPH scavenging and β-carotene-linoleate bleaching method, but the highest reducing powder was found in oil prepared from chilling method. Marina et al. (2008) identified the following phenolic acids in VCO which may be responsible for antioxidant activity: caffeic, p-coumaric, ferulic, protocatechuic, syringic, and vanillic acids. The commercial coconut oil showed the significant amount of catechin and caffeic, p-coumaric, and ferulic acids (Seneviratne and Sudarshana-Dissanayake 2008).

Yeap et al. (2015) administrated the VCO (10 mL/kg body weight) to mice which undergone the forced swim stress test. These mice had restored the oxidative stress within 7 days. They showed the increased amount of brain antioxidants and reduced concentration of brain 5-hydroxytryptamine. VCO lowered the lipid peroxidation and improved the activity of superoxide dismutase in mice serum due to increased amount of antioxidant enzymes, which also minimized the risk of inflammation in VCO-treated mice (Yeap et al. 2015).

### 19.2.6 Coconut Milk

It is milk-white cloudy liquid extract obtained from the manual or mechanical force of coconut meat with or without the addition of water (Narataruksa et al. 2010). Basically, it is oil-in-water emulsion which is prepared by steeping the grated coconut meat in hot water followed by filtration. It is an emerging milk substitute in desserts and nutritional ingredient for several processed products such as jam spread, syrup, cheese, desserts, etc. (Muda 2002). In addition to fat, sugars, ash, and water, the coconut milk contains the fair amount of antioxidants which has promoted its utilization in products vulnerable to lipid oxidation (Simuang et al. 2004; Peamprasart and Chiewchan 2006; Waisundara et al. 2007). The antioxidant potential (DPPH, ferric reducing antioxidant power (FRAP), oxygen radical absorbance capacity (ORAC), and TPC) of coconut milk was found higher than cow and goat milk (Alyaqoubi et al. 2015). The antioxidant activity in coconut milk is attributed to phenolic compounds which basically come from coconut testa (Nadeeshani et al. 2015). Seneviratne et al. (2009) revealed the higher quantity of individual phenolic compounds in coconut milk compared to oil. Therefore, coconut milk can be a promising food in the future which would have potential to inhibit the oxidative damage and risk of degenerative diseases.

### 19.2.7 Coconut Cake

The residual coconut meal left while producing the coconut milk and oil is termed as coconut cake or coconut oil cake. A little research work has been conducted about the antioxidant activity of coconut cake – a potential source of edible protein in diet (Angelia et al. 2010). Seneviratne et al. (2016) recommended the coconut cake as a thermally stable and natural antioxidant to preserve the foods. In this study, the sunflower oil was enriched using similar concentration of antioxidant compounds like butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and tertiary butylhydroquinone (TBHQ) in addition to coconut cake (CC), and after 2 h, the coconut cake retained 96% of its initial colour intensity compared to BHT (89%). The authors observed the following variation in thermal stability of antioxidants: BHT $<$ BHA $<$ CC $<$ TBHQ. Coconut cake was found to prevent the lipid peroxidation in several food matrices due to its antioxidant activity.

In another investigation, the coconut cake contained prolamin, albumin, globulin, glutelin-1, and glutelin-2 as protein fractions which exhibited antioxidant potential (Li et al. 2018). The prolamin as well as glutelin-1 and glutelin-2 had good radical scavenging and reducing power potential, while the higher ion chelating ability was found in globulin and prolamin besides having excellent nutritional value in all fractions. Further, DNA was protected from oxidative damage from all protein fractions except glutelin-2. The peptides derived from globulin and glutelin-2-fractions contained even the amino acids showing good antioxidant activity, as examined using LC-MS/MS. The authors recommended the usage of coconut cake in functional food industry (Li et al. 2018); however, in vivo studies of these antioxidant compounds must be conducted in the future for insightful understanding.

### 19.2.8 Coconut Sap (*Neera*)

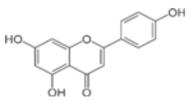
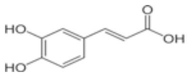
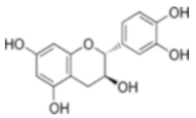
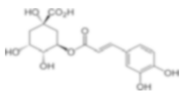
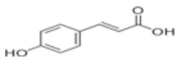
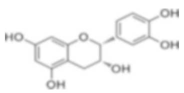
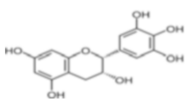
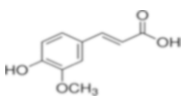
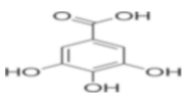
Coconut sap, also known as *neera*, is the sweet exuded sap or fluid or secretion or juice which is procured by tapping the closed spadix of palm. The sap exudes from blossoms before they mature into the coconuts (Misra 2016). The sap is rich in amino acids, sugars, minerals, inulin, vitamins, and dietary fibre in addition to phytochemicals like anthocyanidin, flavonoids, and polyphenols. The fresh sap is utilized for making alcoholic beverage, known as toddy. Devi et al. (2015) reported that coconut sap contained potent reactive oxygen species scavenging activity, showing their possible use as a functional ingredient in food processing as it has low glycaemic index. The antioxidant activity of coconut sap was found to vary from 0.299 to 0.355 mM TE per 100 mL (Augustine and Hebbar 2014). It contained ascorbic acid (20.6 mg/L) which decreased due to reduced yeast activity, whereas the TPC values increased from 0.34 g/L to 1.24 g/L due to metabolic products during fermentation.

## 19.3 Characterization of the Chemical Compound(s) Responsible for Antioxidant Proprieties and the Pathways Involved in the Biological Activities

As discussed above, the phenolic compounds, antioxidant vitamins, and amino acids are the main bioactive compounds contributing to the antioxidant properties of different parts of coconut. Among these, the major chemical compounds in coconut along with their structures are presented in Table 19.3. The secondary metabolites of the plants are known as the polyphenolic compounds which vary from phenolic acids to the polyphenols such as anthocyanins, flavonoids, flavanols, flavonols, tannins, and so on. The polyphenols demonstrate numerous biological activities such as anti-ageing, anticancer, antidiabetic, anti-inflammatory, etc. on the account of their activation of transcription factors and gene expression, free radical scavenging, metal sequestration, and regulating the enzymatic activity and signal transduction (Działo et al. 2016).

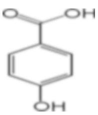
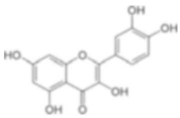
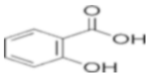
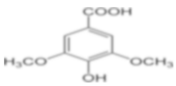
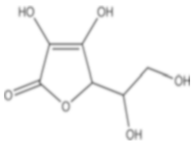
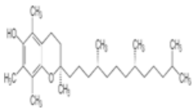
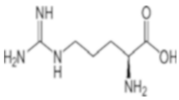
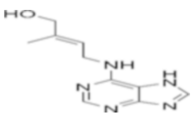
Quercetin and catechin were the major antioxidant compounds found in coconut (cultivar yellow dwarf), identified using UPLC-MS (Bezerra dos Santos Oliveira et al. 2013). Coconut water contained biomolecules like gibberellins, trans-zeatin, trans-zeatin O-glucoside, dihydrozeatin, dihydrozeatin riboside, benzylaminopurine, and ortho-topolin riboside (Liya et al. 2006, 2008), whereas (+)-catechin and (−)-epicatechin were found in coconut water at concentration 0.344 and 0.242 μg/mL, respectively (Chang and Wu 2011), whereas Wu and Hu (2009) considered the salicylic acid as phytohormone in coconut water. L-Arginine (30 mg/dL) and ascorbic acid (15 mg/100 mL) were also found in coconut water which decreases the free radical generation and lipid peroxidation (Das et al. 2001; Salil and Rajamohan 2001). Leong and Shui (2002) found the ascorbic acid in minute amount (0.7 and 0.9 mg/100 g) in coconut water and meat, respectively. Further, coconut water was found to contain various cytokinins mainly kinetin, trans-zeatin, and their derivatives (Yong et al. 2009) among which kinetin being a strong antioxidant is very well known for potent anti-ageing effects (Ge et al. 2005). Kinetin slows down the commencement of many cellular and biochemical reactions linked to cellular ageing of human skin fibroblast cultures and therefore used to cure the sun-damaged skin (McCullough and Weinstein 2002). It prevented the DNA oxidative damage by inhibiting the generation of 8-oxo-2'deoxyguanosine – a chemical marker for DNA oxidative damage. It also inhibited the oxidative and glycoxidative damage of in vitro protein, thereby resulting in the possibility of controlling the oxidative

**Table 19.3** Major chemical compounds responsible for antioxidant activities of coconut

| S. No. | Chemical compounds | | Coconut parts/ extracts | References |
|---|---|---|---|---|
| | Name | Structure | | |
| **A. Phenolic compounds** | | | | |
| **1** | Apigenin |  | Coconut oil cake extract | Seneviratne et al. (2016) |
| **2** | Caffeic acid |  | Coconut meat, oil, oil cake extract | Seneviratne et al. (2009, 2016) and Mahayothee et al. (2016) |
| **3** | Catechin |  | Coconut water, husk fibre, whole coconut fruit; oil cake extract | Esquenazi et al. (2002), Chang and Wu (2011), Bezerra dos Santos Oliveira et al. (2013), Mahayothee et al. (2016) and Seneviratne et al. (2016) |
| 4 | Chlorogenic acid |  | Coconut oil cake extract | Seneviratne et al. (2016) |
| **5** | p-Coumaric acid |  | Coconut meat, oil cake extract | Mahayothee et al. (2016) |
| 6 | Ellagic acid |  | Coconut oil cake extract | Seneviratne et al. (2016) |
| **7** | Epicatechin |  | Coconut water, husk fibre | Esquenazi et al. (2002) and Chang and Wu (2011) |
| **8** | Epigallocatechin |  | Coconut oil | Seneviratne et al. (2009) |
| **9** | Ferulic acids |  | Coconut oil, oil cake extract | Seneviratne et al. (2009, 2016) |
| **10** | Gallic acid |  | Coconut meat, oil, oil cake extract | Seneviratne et al. (2009), 2016) and Mahayothee et al. (2016) |

(continued)

**Table 19.3** (continued)

| S. No. | Chemical compounds | | Coconut parts/ extracts | References |
|---|---|---|---|---|
| | Name | Structure | | |
| **11** | p-Hydroxybenzoic acid |  | Coconut oil, oil cake extract | Seneviratne et al. (2009, 2016) |
| **12** | Quercetin |  | Whole coconut fruit | Bezerra dos Santos Oliveira et al. (2013) |
| **13** | Salicylic acid |  | Coconut water, meat | Mahayothee et al. (2016) |
| **14** | Syringic acid |  | Coconut oil, oil cake extract | Seneviratne et al. (2009, 2016) |
| **B. Vitamins** | | | | |
| **15** | Ascorbic acid |  | Coconut water and meat | Das et al. (2001), Salil and Rajamohan (2001) and Leong and Shui (2002) |
| **16** | Tocopherols |  | Coconut oil | Arunima and Rajamohan (2014) |
| **C. Amino acids** | | | | |
| **17** | L-Arginine |  | Coconut water | Das et al. (2001) and Salil and Rajamohan (2001) |
| **D. Phytohormones** | | | | |
| **18** | Cytokinins |  | Coconut water | Yong et al. (2009) |
| **E. Proteins** | | | | |
| **19** | Globulin and glutelin-2 | – | Coconut cake | Li et al. (2018) |

damage of unsaturated fatty acids inside the cell membranes (Verbeke et al. 2000; Yong et al. 2009).

Coconut oil is rich in mainly α-tocopherol and lauric acid responsible for biological action (Tangwatcharin and Khopaibool 2012; Arlee et al. 2013; Arunima and Rajamohan 2014). Almost 50% of fatty acids in coconut oil is lauric acid ($C_{12}H_{24}O_2$) – the saturated medium-chain fatty acid which possesses the distinct properties unlike long-chain fatty acids (Dayrit 2014). Lauric acid when metabolized converts to the compound monolaurin which has antimicrobial properties. Lappano et al. (2017) showed the activation of antiproliferative and pro-apoptotic effects in the breast and endometrial cancer cells from lauric acid. The acid enhances the concentration of reactive oxygen species; stimulates the phosphorylation of EGFR, ERK, and c-Jun; and induces the expression of c-fos. Lauric acid also supported the generation of stress fibre through Rho-associated kinase-mediated pathway linked to death of apoptotic cells. However, much work is still needed for the further validation of the anticancerous effect of lauric acid. When extracted under hot conditions, the oil was found to contain caffeic, ferulic, gallic, p-hydroxybenzoic, and syringic acids as well as (+)-catechin, (+)-epicatechin, and (−)-epigallocatechin, while the cold-extracted oil contained gallic, syringic acids, and (−)-epigallocatechin (Seneviratne et al. 2009). On the other hand, Mulyadi et al. (2018) analysed VCO and found the following phenolic compounds, caffeic, p-coumaric, ferulic, protocatechuic, vanillic, and syringic acids, which are responsible for the antioxidant characteristics. These trap the intermediate peroxyl radicals and hinder the autoxidation of lipids in the following manner: (i) phenolic compound gives a hydrogen proton to peroxyl radical for generating hydroperoxide and aroxyl radicals; and (ii) aroxyl radical are subjected to radical-radical coupling forming peroxide products (Seneviratne and Sudarshana-Dissanayake 2008). Vysakh et al. (2014) examined the VCO-derived polyphenolic fraction for their protective efficacy against adjuvant-induced arthritic rats. VCO exhibited the better oedema inhibition without any toxicity at 80 mg/kg on the 21st day of adjuvant arthritis. Moreover, VCO also decreased the expression of inflammatory genes like COX-2, iNOS, IL-6, and TNF-α and the level of thiobarbituric acid reactive substances and accelerated the amount of total white blood cell (WBC) count and C-reactive protein which resulted in the suppression of inflammatory and reactive mesothelial cells. Rats when given VCO in their diet revealed less formation of oedema and cellular infiltration. VCO polyphenols improve the sulfhydryl form glutathione (GSH) and superoxide dismutase (SOD) activity which retains the integrity of cellular membranes. Thus, the VCO polyphenols have a potential for being used as an anti-arthritic agent. Famurewa et al. (2018) investigated about the effect of VCO polyphenols on nephrotoxicity and inflammation induced by cadmium (Cd) in rats. Polyphenols were given to rats before and together with Cd (5 mg/kg, orally) for 7 weeks. Cd-induced nephrotoxicity and oxidative stress increased the concentration of creatinine, urea, and uric acid in blood while suppressing renal activities of antioxidant enzymes and GSH with prominent increase in malondialdehyde (MDA). The administration of phenolic compounds restored the level of creatinine, urea, and uric acid on the account of its antioxidant and radical trapping properties and protected the kidney from Cd intoxication. Rahim et al. (2017) fed the Wistar rats with VCO and found significant increase in their cognitive functions. The rats were having decreased acetylcholinesterase, lipid peroxidase [malondialdehyde (MDA)], and nitric oxide (NO), whereas the levels of acetylcholine (ACh), superoxide dismutase (SOD), catalase, glutathione (GSH), and glutathione peroxidase (GPx) were increased. This resulted in the improved memory in rats compared to the control, and this effect was mediated through increased levels of antioxidants and reduced oxidative stress. Nair et al. (2016) determined the effect of VCO on formalin-induced chronic inflammation and cyclophosphamide (CTX)-induced systemic toxicity in murine models and found the reduction of formalin-induced paw oedema in mice similar to diclofenac. VCO also reduced the levels of creatinine, urea, thiobarbituric acid reactive substances (TBARS), and liver marker enzymes in blood, induced by CTX, whereas the concentrations of catalase, superoxide dismutase, and glutathione peroxidase activities were increased. This showed the potential of VCO to protect from CTX-induced toxicity. Thus, the polyphenols from VCO exhibited several biological functions by increasing the level of antioxidants like ascorbic acid, L-arginine, and GSH and antioxidant enzymes like SOD, catalase, etc. in the rats (Illam et al. 2017; Rahim et al. 2017).

Costa et al. (2010) reported the presence of alkaloids, flavonoids, leucoanthocyanidins, phenols, saponins, steroids, tannins, and triterpenes in the coconut mesocarp or fibre, while other studies revealed the compounds like catechins, epicatechins, flavonoids, and tannins contributing to biological activity (Mendonca-Filho et al. 2004; Freitas et al. 2011). These compounds are the strong inhibitors of cell growth having anticancer activity (Nihal et al. 2005; Qanungo et al. 2005). However, the copra extract and oil did not contain the flavonoids, steroids, tannins, terpenoids, and acidic compounds but contained in moderate amount the alkaloids, saponins, and resins (Ghosh et al. 2014). Seneviratne et al. (2016) found only the phenolic acids or flavonoids in the extract of coconut oil cake which contained apigenin (56.7 mg/kg), caffeic acid (225.7 mg/kg), catechin (26.9 mg/kg), chlorogenic acid (240.8 mg/kg), p-coumaric acid (6.2 mg/kg), ellagic acid (3.8 mg/kg), ferulic acid (13.8 mg/kg), gallic acid (23 mg/kg), p-hydroxybenzoic acid (129 mg/kg), and syringic acid (3.6 mg/kg). Among these, the phenolic compounds having ortho-diphenyl functionalities are very potent antioxidant because phenolic group can easily donate the hydrogen radical to neutralize the substrate radicals resulting in phenoxy radical. For stabilization of formed radical, the intra-molecular hydrogen bonding can form with ortho-phenyl group generating the cyclic intermediate. In another study by Li et al. (2018), the fractions of coconut cake protein, globulin and the glutelin-2, exhibited the higher antioxidant properties which contained 8 and 12 peptides, respectively, having predominant 5–8 amino acids. Some peptides, viz. RPFNLFHK, LPILR, VIEPR, VVLYR, and ADVFNPR, demonstrated the higher superoxide radical scavenging activity which can protect the vascular cells from hydrogen peroxide-induced injury (Tapal et al. 2016). The peptide ADVFNPR as identified from palm kernel showed the high scavenging capacity against hydroxyl radical ($IC_{50}$: 22.16 mg/mL) (Zheng et al. 2017). Besides this, the coconut cake protein fractions – prolamin and globulin – prevented the oxidative damage of DNA due to their higher chelating ability on $Fe^{2+}$ and scavenging the free radicals generated during oxidation reactions (Li et al. 2018). Further, Arivalagan et al. (2018) identified 28 phenolic compounds including 12 flavonoids and 16 phenolic acids. Among these, the p-coumaric, ferulic, and protocatechuic acids were major phenolic acids, and apigenin, catechin, and kaempferol were the main flavonoids found in coconut testa.

## 19.4 Health Benefits

Coconut and its products find extensive use in food industry due to their distinct properties. Coconut is always a part of traditional medicine because its each part offers the health benefits. However, the positive effects of coconut oil are still debatable.

### 19.4.1 Coconut Husk

The husk fibre derived from coconut is employed to treat diarrhoea, oral asthma, and renal inflammation. It is also used as topic ointment for dermatitis, abscesses, and other injuries (Esquenazi et al. 2002; Lima et al. 2015).

### 19.4.2 Coconut Oil

The distinct therapeutic and nutritional properties of coconut oil include its quick digestion, absorption, and oxidizable nature resulting in decreased accumulation of fat in the body. It is considered one of the best massage oils due to its higher skin penetration rate. The major health benefits offered by coconut oil are mainly due to its lipid portion which is comprised of 8–10% unsaturated fatty acids (mainly oleic and linoleic acid) and 90–92% saturated fatty acids (lauric acid). Coconut oil exhibits antimicrobial and antiviral characteristics due to the conversion of lauric acid (C12:0) – a medium-chain fatty acid – into the compound monolaurin which possess these properties (Wallace 2019). Lauric acid also exhibited the anticancer activity by inducing the apoptosis (Fauser et al. 2013). Further medium-chain fatty acids possess higher solubility compared to longer-chain fatty acids which permits the several lipases. This results in the better and quicker digestion of glycerides. Likewise, the hydrolytic products would directly reach the liver and can be utilized for energy production. Thus coconut oil can modulate the fatty acid metabolism by decreasing the lipogenesis and improving the catabolism of fatty acid (Arunima and Rajamohan 2014). However, the only disadvantage with coconut oil is the poor level of essential fatty acids.

No doubt coconut oil has multiple beneficial uses, but the effect of higher saturated fats on health is still debatable. The serum lipid profile of coronary artery disease (CAD) patients who consumed coconut and sunflower oil was almost similar, and there was also no significant difference in the antioxidant levels and vascular function (Sabitha and Vasudevan 2010; Vijayakumar et al. 2016). Norton et al. (2004) showed the decreased risk of heart disease on the consumption of coconut oil due to the modification of lipid profile. Another study conducted by Assuncao et al. (2009) revealed the decrease of abdominal obesity and improvement in LDL/HDL cholesterol ratio in women subjects administered to coconut oil, while the soya bean oil group demonstrated reduced level of HDL cholesterol and increased level of total and LDL cholesterol. On the contrary, Eyres et al. (2016) did not support the use of coconut oil to lower the risk of heart disease. They focussed on the quantity rather than quality of cooking oil contributing to CAD risk (Sabitha and Vasudevan 2010). Few studies supported the use of coconut oil to prevent the atopic dermatitis and in oil pulling for inhibiting the dental caries (Peedikayil et al. 2015; Chew 2019). The diet rich in coconut oil inhibited the deposition of body fat and also prevented the insulin resistance (Kochukuzhiyil et al. 2010).

The biologically active non-glyceride components of coconut oil like carotenes, polyphenol, phytosterols, tocopherols, etc. are highly beneficial to health which is present in higher amount in VCO (Nevin and Rajamohan 2004). The administration of VCO to animals increased the level of HDL cholesterol compared to copra and groundnut oil (Nevin and Rajamohan 2006, 2009). Further, the VCO-fed mice decreased the total LDL + VLDL cholesterol but increased the concentration of Apo A1 and HDL cholesterol than the other groups fed with copra, olive, and sunflower oil. Apo A1 is the major protein found in serum HDL which is inversely related to risk of premature atherosclerosis (Arunima and Rajamohan 2012). VCO is highly beneficial in treating the hair-fall issues, mainly due to the protein loss or ultraviolet (UV) exposure, but many efforts must be taken by scientists for the confirmation of this effect. The effect of coconut oil or VCO on cardiovascular diseases is still questionable, and observational studies are needed to confirm its positive effects on health.

### 19.4.3 Coconut Water

Coconut water possesses plenty of functional compounds such as free amino acids (L-arginine), electrolytes, enzymes (catalase, dehydrogenase, polymerases, etc.), minerals, phytohormones (cytokinins), polyphenols, proteins (globulin, albumin, glutelin, and prolamin), sugars, and vitamins (ascorbic acid) (Anurag and Rajamohan 2003; Sandhya and Rajamohan 2006; Bamunuarachchi and Ranaweera 2007; Bhagya et al. 2010). It is one nutritious rehydration medium which is easily accepted by the body. It is recommended to treat diarrhoea in children and also decreased the risk of heart diseases. Studies reported the anti-ageing, hypocholesterolaemic, antithrombotic, and anticarcinogenic effects of cytokinins, viz. kinetin and trans-zeatin (Vermeulen et al. 2002; Anthony and Rajamohan 2003; Prathapan and Rajamohan 2010). Alleyne et al. (2005) revealed the significant role of coconut water in regulating hypertension. Sandhya and Rajamohan (2008) found that coconut when matured had water which would be better in hypolipidaemic activity in cholesterol-fed rats due to the higher concentration of bioactive compounds. Similarly, Preetha et al. (2013) reported the significant hypoglycaemic effect in diabetic rats when administrated with matured coconut water than one obtained from tender coconut. The earlier one also decreased the pancreas damage induced by alloxan and stimulated beta-cell regeneration. L-Arginine aids the variations in the levels of lipids, blood glucose, and coagulation factors via the nitric oxide availability. Further, diabetes adversely affects the kidney which can be reversed significantly by the daily intake of coconut water (Nwangwa 2012).

### 19.4.4 Coconut Kernel

Coconut kernel is being used as a culinary ingredient in different regions of Asia. The presence of macro- and micronutrients like vitamins (ascorbic acid, thiamine, vitamin A, and tocopherol), minerals (calcium, chlorine, copper, iron, magnesium, manganese, phosphorus, potassium, and sulphur), calories, phenolic compounds, and phytohormones is the reason for its health benefits. L-Arginine found in coconut kernel proteins contributes to the hypolipidaemic effect. The kernel protein also decreased the levels of enzymes, glucose, and insulin, thus regulating the carbohydrate metabolism in diabetic rats (Salil et al. 2011). Mini and Rajamohan (2002) revealed that coconut kernel proteins demonstrated the cardioprotective effect on isoproterenol-induced myocardial infarction of rats. The oxidative stress and myocardial infarction-related inflammatory responses were also decreased significantly by the supplementation of kernel protein. The phenolic compounds and phytohormones found in coconut kernel contributed to inhibit Alzheimer's disease (Fernando et al. 2015).

### 19.4.5 Others

The coconut kernel is also rich in dietary fibre which has the significant hypocholesterolaemic effect. The hemicelluloses component of fibre is contributing to the reduction of cholesterol (Sindhurani and Rajamohan 2000). The kernel fibre also prevented the 1,2-dimethylhydrazine-induced colon carcinogenesis (Manoj et al. 2001). The coconut cake was also found to reduce the risk of colon carcinogenesis (Nalini et al. 2004). The sugars obtained from coconut sap have α-amylase inhibitory activity and therefore are considered as a therapeutic agent to diagnose the type II diabetes mellitus.

## 19.5 Conclusion

The coconut palm and its products are the significant source of antioxidant compounds resulting in the promotion of health. Coconut husk and shell are rich in polyphenols, whereas copra contains the phytochemicals like alkaloids, flavonoids, phenols, saponins, and tannins. Coconut oil, particularly the virgin coconut oil, offers positive effects on health due to its distinct fatty acid composition which possesses the medium-chain fatty acid lauric acid having antibacterial properties. Coconut water in addition to being refreshing decreases the cardiovascular disease risk, while the neera contains amino acids, sugars, minerals, inulin, vitamins, and dietary fibre in addition to phytochemicals. The coconut kernel proteins exhibited the cardioprotective and antidiabetic characteristics, while dietary fibre from kernel demonstrated the hypocholesterolaemic effect. However, the discussed health benefits have been based on animal studies, and the concrete efforts are needed to validate these therapeutic properties along with their respective mode of action. Traditional knowledge about positive health effects of coconut must be proved and validated clinically. Therefore, the controlled research investigations must be focussed in the future to determine the impact of coconut products to cure the several chronic diseases in a promising way.

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# Walnut

# 20

Vidisha Tomer, Ashwani Kumar, Kritika Gupta, Swati Shukla, and Shafiya Rafiq

**Abstract**

Walnuts had been known for their explicable taste and undebatable health benefits since ancient times. Modern techniques have added evidence to this long-perceived notion by identifying and characterizing the compounds which are responsible for the varied health benefits to human health. Walnuts contain variety of nutritional and non-nutritional components which exhibit antioxidant properties. The polyphenol and flavonoid content of walnuts is higher than many popular nuts. These enclose 10% of their energy as alpha-linolenic acid (ALA). The benefits of walnuts are not achieved through single nutrient, but rather is the outcome of the functional synergy of the phytochemicals enclosed in a complex matrix acting at various metabolic and physiological levels in human body. ALA can be metabolized into several bioactive compounds like oxylipins, which protect microglial cells from inflammation and are effective against cardiovascular diseases; phytomelatonin, known for its anticancer effect; ellagitannins, metabolize into urolithin A and B and protect against obesity, diabetes, and cardiovascular diseases (CVD). Phytosterols are associated with cholesterol-lowering impact through several proposed mechanisms. Non-sodium minerals are associated with better cardiometabolic health. Present chapter highlights the

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antioxidant potential of walnuts and characterize the compounds exhibiting antioxidant properties. Health benefits of walnut consumption are also covered.

**Keywords**

Walnut · Phytochemicals · Health benefits · Cardiovascular diseases · Antioxidant potential

## 20.1 Introduction

Common names: Walnut, *Akhrot* in Hindi and Urdu; *akrodu*, *akrotu* in Kannada; *akroda* in Marathi; *Sano okhar* in Nepali; *Akhoda*, *Akhota* in Sanskrit; *Akarottu* in Tamil; *Akarottu* in Telugu
Botanical name: *Juglans regia*
Synonyms: *Juglans kamaonia*, *Juglans orientis*, *Juglans fallax*

The name walnut is reserved as the common name of trees belonging to genus *Juglans*. Walnut is a tree nut grown majorly in temperate climatic zones of North and South America, Europe, and Asia. Its trees are grown majorly for nuts and timber. Most relevant species of commercial significance include *J. regia* (timber and nuts) and *J. nigra* (timber) (Verma 2014). The nut is used in different forms throughout the world. In the UK, pickled walnuts are prepared by preserving fresh unripe fruits with their husks in vinegar, while in Armenian cuisine, sugar syrup is used for the preservation of immature fruits along with husks and is eaten whole. In Italy, walnuts have been used as flavorings in liqueurs namely Nocino and Nocello. A walnut pasta sauce known as *Salsa di Noci* originated and is consumed in Liguria. Walnut sauce is prepared by grinding with other ingredients has been also reported in Georgia.

### 20.1.1 History

Historically, walnuts have been known to mankind dating back to 7000 BC. As these were reserved as delicacies for the riches, it has long history of travel throughout the world. It has its origin in Persia (Iran) in southwest Asia, which is also signified by its common name, Persian walnut (Pollegioni et al. 2017). The scientific name of the Persian walnut is *Juglans regia*, where *Juglans* is derived from a Latin word *Jovis glans* meaning "Jupiter's acorn" or nut fit for god. Before this, in Latin, walnuts were called as *nux Gallica,* meaning Gallic nut. This nut is native from the Balkans in Southeast Europe, Southwest and Central Asia, to the Himalayas, and Southwest China. Walnuts were introduced to Greece, from where these were taken to Rome. It was introduced in England from Gaul and Italy, and got its name "walnut" which is derived from olden English word Welsh-nut*,* literally meaning "foreign nut." As it travelled along with English businessmen, through the silk route to different parts of the world, the misnomer "English walnut" developed. In reality, these were never grown commercially in England (Bottema 2000). Two commercially viable species of walnuts include English/Persian walnut and Black walnut (native to North America).

## 20.1.2 Production

The total world tree nut production (kernel basis) was estimated to be 4,187,108 metric tons in 2017–2018. The USA is the leading producer of tree nuts, with a share of 38% in total world produce (APEDA 2018). In this, the production of walnut was estimated to be 871,850 metric tons on kernel basis (Fig. 20.1a). China and the USA are the world's top walnut-producing countries with 42% and 29% of global

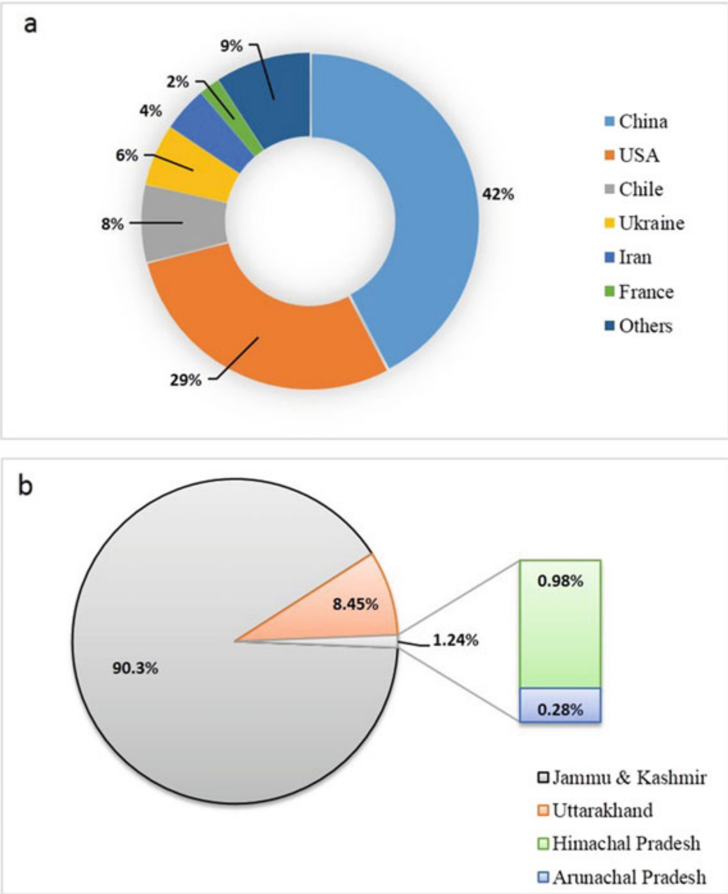



**Fig. 20.1** Production share of walnuts on kernel basis (**a**) In world 2017–2018 (USDA 2019) (**b**) India 2016–2017 (APEDA 2018)

production share (USDA 2019). In India, walnut farming is confined to the hilly regions of the country, majorly Jammu and Kashmir (Fig. 20.1b). Himachal Pradesh, Uttarakhand, and Arunachal Pradesh are the minor producers of walnut in India (APEDA 2018). Indian domestic share of the walnuts was expected to be 34,000 metric tons in the year 2018–2019 (USDA 2019). The country has exported 1874.87 MT of walnuts to the world for the worth of Rs. 66.75 crores during the year 2018–2019 (APEDA 2019).

### 20.1.3 Botanical Description

Walnut belongs to family *Juglandaceae*, also known as the walnut family. Deep, sandy, loamy, irrigated, and well-drained soil, rich in organic matter, is preferred by this tree. It is also resistant to a wide pH range and can be grown on a pH range of 5–8. The average commercially grown walnut tree needs 1270 mm (50 inches) of precipitation every year. It is a deciduous tree which grows up to 25–35 m high, with a trunk diameter of 2 m (Verma 2014). The tree trunk is usually shorter with a broad crown when cultivated. It is comparatively higher and thinner in dense forest competition although. The young walnut tree has characteristic olive-brown branches with smooth bark. Older branches are silver-gray in color, with a rougher texture and characteristic broad fissures. The tree has monoecious flowering pattern. The male flowers are 5–10 cm long and grow as drooping catkins, while the female flowers grow in the clusters of two to five. These grow to green fruits (pseudodrupe) in autumn which ripen into brown corrugated nuts with green husk. On complete ripening, the whole fruit along with the husk falls in autumn. The seed has a hard shell with a large edible portion inside it. There are 21 species of walnut throughout the world which are divided in to four major sections/species: *Rhysocaryon* (black walnut), *Cardiocaryon* (Japanese, Manchurian, Chinese walnuts), *Trachycaryon* (Butternut), and *Juglans* (Persian/English walnut).

Walnut tree is found in West Asia, west China, and the Himalayas at altitudes of 1000–3300 m.

### 20.1.4 Composition of Walnut

The walnut fruit consists of three distinct parts, that is kernel covered with a thin brown skin enveloped in a hard shell. The edible portion (kernel) is a two-lobed, ivory-colored seed. It is covered with firmly attached thin brown skin. The kernel with skin is enclosed in a thick hard brown shell. The shell serves as the natural protectant for the fruit.

Kernel composition of different varieties of walnut was analyzed by Pereira et al. (2008). It was observed that the moisture content varied from 3.85 to 4.50 g/100 g on fresh weight basis. Total fat, proteins, carbohydrates, and ash varied from 68.8 to 72.14 g/100 g, 14.38% to 15.8%, 3.75 to 7.16 g/100 g, and 3.3 to 4.26 g/100 g, respectively, on fresh weight basis (Pereira et al. 2008).

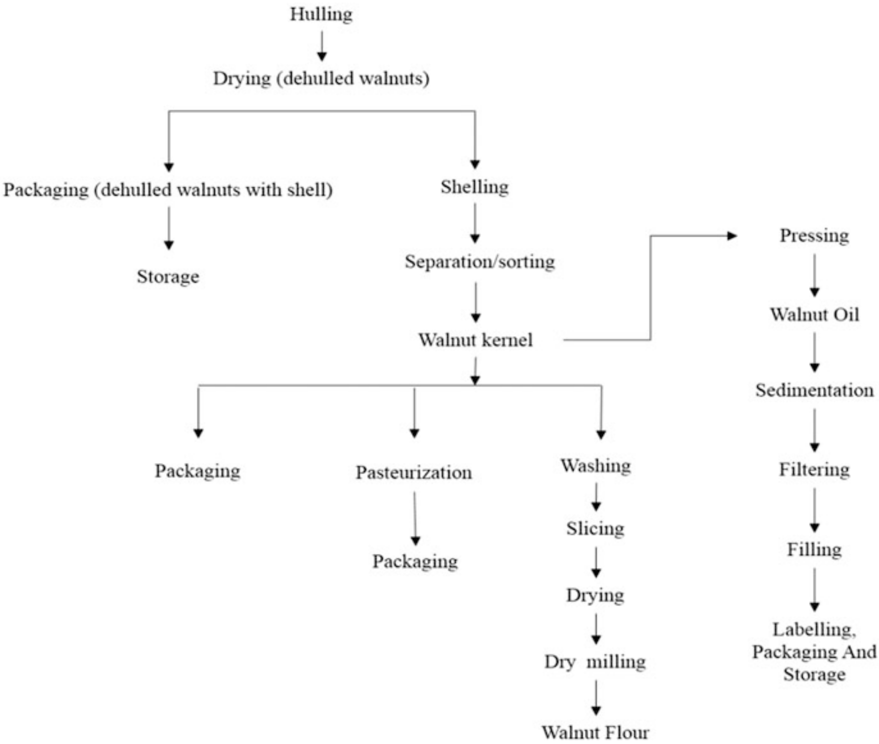



**Fig. 20.2** Schematic diagram on processing of walnut

The kernels are pressed to obtain walnut oil, and an oil content of approximately 620–740 g $kg^{-1}$ kernel was reported for commercial walnut varieties (Martínez et al. 2010). The amount of oil increases with the stage of kernel development and follows a double sigmoid curve. Salgin and Salgin (2006) observed extraction rate up to 685 g $kg^{-1}$ using supercritical fluid extraction. Walnut oil is rich in triacylglycerols (TAG) (up to 980 g $kg^{-1}$of oil), constituting majorly of polyunsaturated acid (PUFA) – 60% linoleic acid (LA), and 18% α-linolenic acid (ALA) and monounsaturated fatty acids (MUFA) – mainly oleic acid – 20% approximately. Among vegetable oils, walnut oil contains largest amount of PUFAs with amounting approximately 78% of the total fatty acid content (Pereira et al. 2008). On characterization, nine TAG species have been identified in walnut oil. The most abundant (~37.7%) TAG in walnut oil is trilinolein followed by dilinoleoyl-oleoyl-glycerol (18.5%) and dilinoleoyl-linolenoyl-glycerol (18.4%) (Martínez et al. 2010).

After extraction of oil from the kernel (Fig. 20.2), walnut flour is attained from the press cake. This flour is rich in proteins (450 g $kg^{-1}$). The proteins in flour can mainly be characterized majorly into glutelins (70% of total proteins), globulins (18%), and comparatively smaller amount of albumins (7%) and prolamins (5%). Walnut protein is a complete protein for adult human as it contains most of the essential amino acids (EAAs). Lysine is the limiting amino acid in walnuts although. This makes walnut protein a less preferable protein for 2–5-year-old children, as it does not suffice their complete nutritional requirements. Another limitation of the walnut protein is its lysine–arginine ratio which is lower in comparison to the vegetable proteins. This is considered as a feature responsible for atherosclerosis development (Martínez et al. 2010).

## 20.2 Antioxidants in Walnut

Free radical is a general term used for reactive oxidant species (ROS). This group include hydroxyl radicals $OH^-$, hydrogen peroxide $H_2O_2$, peroxyl radical ($ROO^{\cdot}$), reactive nitrogen species including nitric oxide ($NO^{\cdot}$). Free radical generation in human cells is a part and parcel of regular physiological processes. Appropriate number of free radical production is necessary to facilitate critical functions like detoxification of liver. However, environmental or physical stress can lead to liberal free radical generation. When reactive oxygen species are overproduced, or the antioxidant defense systems are inefficient, accumulation of free radicals occur that lead to oxidative damage to cellular protein, DNA, and/or RNA. This condition, referred to as oxidative stress/damage is not the only outcome. Free radicals may start regulating the activities of transcription factors and may result as contributory factor toward disease development, including all types of cancers, arthritis, inflammatory diseases, heart diseases, ischemic diseases, AIDS, and neurological disorders (Lobo et al. 2010; de Haan et al. 2003; Tiwari 2001).

Antioxidants either delay or inhibit oxidation. The major mechanisms of action include scavenging peroxidation initiating species, chelating metal ions, breaking chain reactions, preventing oxygen concentrations (Brewer 2011; Lobo et al. 2010). Previous studies have established the antioxidant potential of leaves, fruits, kernels, and husk extracts of walnuts (Fernández-Agulló et al. 2013; Zhang et al. 2009; Arcan and Yemenicioğlu 2009; Pereira et al. 2007). The data for the antioxidant content and activity of different nuts from different assays is given in Tables 20.1 and 20.2. This section describes antioxidant potential of different parts of walnut.

### 20.2.1 Kernel

Walnut kernel is rich in antioxidants. In comparison to the other hard-shell nuts, walnut contains higher amount of antioxidants (Şen and Karadeniz 2015). The antioxidant capacity and antioxidant content of different tree nuts is given in Tables 20.1 and 20.2. Blomhoff et al. (2006) compared the total antioxidant content of different nuts and found that walnuts had the maximum (23.07 mmol/100 g), followed by peanuts (8.33) and chestnuts (4.66).

Pereira et al. (2008), studied six walnut cultivars and reported that at a concentration of 0.5 mg/ml, the aqueous extracts of walnut showed a radical scavenging activity from 90.2% to 92.6%. The oxygen radical absorbance capacity (ORAC) in

**Table 20.1** Antioxidant activity of different nuts

| Nuts | ORAC assay (μmol TE/g) | TRAP (mmol Trolox/kg) | FRAP (μmol Fe2+/g) | FRAP (mmol/100 g) | AUC value (μmol trolox equivalents/100 g d.w.) | AUC value (μmol trolox equivalents/100 g d.w.) |
|---|---|---|---|---|---|---|
| | | | | | Aqueous extract | Ethanolic extract |
| Walnuts | 135.41 | 31.85 | 453.94 | 23.1 | 2319 | 2124 |
| Almonds | 44.54 | 6.33 | 41.34 | 0.41 | – | – |
| Brazil nuts | 14.19 | – | – | 0.15 | – | – |
| Cashew nuts | 19.97 | – | – | 4.67 | – | – |
| Hazelnuts | 94.45 | 6.9 | 42.31 | 0.7 | 1783 | 1280 |
| Macadamias | 16.95 | – | – | 0.42 | – | – |
| Peanuts | – | 3.3 | 15.46 | – | – | – |
| Pines | 7.19 | 1.54 | 13.42 | 0.37 | – | – |
| Pistachios | 79.83 | 25.92 | 192.67 | 1.27 | 3111 | 1627 |
| | Alasalvar and Shahidi (2009) | Pellegrini et al. (2006) | Pellegrini et al. (2006) | Alasalvar and Shahidi (2009) | Arcan and Yemenicioğlu (2009) | Arcan and Yemenicioğlu (2009) |

**Table 20.2** Content of phytochemicals in different nuts

| Nuts | TAC (mmol/100 g) | TPC (mg GAE/g) | TPC (mg/100 g) | TPC (mg GAE/100 mg) | TFC (mg/100 g) | Flavonoids (mg/100 g) | | | Phenolic acids (mg/100 g) | | Tocopherols (mg/100 g) | Phytosterols (mg/100 g) | β-Sitosterol (mg/100 g) | Campesterol (mg/100 g) | Stigmasterol (mg/100 g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Walnuts | 23.07 | 15.56 | 1602 | 1558–1625 | 2.71 | 3–6.5 | 2.74 | 0.54 | 39.11 | 36 | 43.72 | 307 | 64 | 7 | 1 |
| Almonds | 0.412 | 4.18 | 261 | 47–418 | 15.24 | 11 | 15.25 | 25.01 | 0.44 | 0.2–0.7 | 28.6 | 271 | 132 | 5 | 4 |
| Brazil nuts | 0.249 | 3.1 | 197 | 112–310 | | | | 0.85 | 11.35 | 11 | 20.15 | 208 | | | |
| Cashewnuts | 0.388 | 2.74 | 242 | 137–274 | 1.98 | 2 | 1.99 | 1.12 | | | 7.1 | 191 | | | |
| Chestnuts | 4.668 | | | 1580–3673 | 0.02 | 0.02 | | | | 4–142 | 59.6 | 800 | | | |
| Hazelnuts | 0.701 | 8.35 | 447 | 291–835 | 11.96 | 12 | 11.99 | 13.21 | 1.87 | 2 | 21.31 | 165 | 89 | 6 | 1 |
| Heart nuts | | | | 148–248 | | | | | | 34–62 | 22.5 | | | | |
| Macadamias | 0.424 | 1.56 | 233 | 46–156 | | | | 137.9 | 3.69 | 4 | 6.15 | 128 | 108 | 8 | |
| Peanuts | | | | 0.1–420 | | 1 | | | | 3.0–6.0 | 29.72 | 284 | | | |
| Pecans | 8.33 | 20.16 | 1588 | 1284–2016 | 34.01 | 34 | 34.01 | 2713.49 | 2052 | 6.0–10.0 | 49.11 | 283 | 89 | 5 | 3 |
| Pines | | 0.68 | 206 | 32–68 | 0.49 | 0.5 | 0.49 | 0.03 | | | 45.8 | 164 | 141 | | |
| Pistachios | 1.274 | 16.57 | 703 | 867–1657 | 14.37 | 16 | 18 | 136.45 | 1.27 | 1 | 39.77 | 184 | 198 | 10 | 5 |
| | Blomhof et al. (2006) | Alasalvar and Shahidi (2009) | Bolling et al. (2011) | USDA database | Alasalvar and Shahidi (2009) | Alasalvar and Bolling (2015) | Bolling et al. (2011) | Bolling et al. (2011) | Bolling et al. (2011) | Alasalvar and Bolling (2015) | Alasalvar and Bolling (2015) | Alasalvar and Bolling (2015) | Bolling et al. (2011) | | |

μmol TE/g of walnuts (135.4) is highest when compared to major nuts including almonds (44.5), brazil nuts (14.2), cashews (20.0), hazelnuts (96.5), macadamia (17), and pistachios (79.8 μmol TE/g) (Bolling et al. 2010). For ferric reducing ability of plasma (FRAP) assay, walnuts reduced 453.9 μmol $Fe^{2+}$/g, 41.3 for almonds, 42.3 for hazelnuts, 13.4 for pines, and 192.7 for pistachios (Bolling et al. 2010). Antioxidant activities (AUC values) of fresh walnuts by Arcan and Yemenicioğlu (2009) was reported to be 7713 ± 176 μmol trolox equivalents/ 100 g DW in aqueous extracts, and 3363 ± 41 μmol trolox equivalents/100 g DW in ethanolic extracts. The methanolic extract of walnut seeds have free radical scavenging capacity of 92.3% after 18-h extraction period (Akin et al. 2013). Another study conducted on different genotypes of walnuts, reported 1.2 ± 0.10% radical scavenging activity of methanolic extract walnut kernels, 63.89 ± 0.1% superoxide radical scavenging activity, and 9.87 ± 1.82% nitric oxide radical scavenging activity (Akbari et al. 2012).

### 20.2.2 Skin

The skin, also known as seed coat, contains the maximum amount of antioxidants (TFC = 51.94 ± 7.95 mg QEs/100 g DW, TPC = 27903.86 ± 5980.09 mg GAEs/ 100 g DW) and protect the kernel against oxidation (Jahanban-Esfahlan et al. 2019; Ebrahimi et al. 2018). Samaranayaka et al. (2008) reported 35.96 ± 5.19 trolox equivalent antioxidant capacity in walnut skin. Thus, on removing the seed coat, the total antioxidant capacity of the nuts is reduced by as much as 90% (Jahanban-Esfahlan et al. 2019; Alasalvar and Shahidi 2009).

### 20.2.3 Shell

The ethanolic extract of walnut leaves had ORAC value of 3423.44 ± 142.52 μmol TE/g, and the reducing power was reported to be 115.86 ± 2.05 μg/ml (Wang et al. 2015). Methanolic extract of walnut shells exhibited a radical scavenging activity of 7.19 ± 0.11%, superoxide radical scavenging activity of 108.12 ± 2.04%, and nitric oxide radical scavenging of 70.26 ± 2.19% (Akbari et al. 2012).

### 20.2.4 Husk

Methanolic extract of walnut husk has been found to exhibit a radical scavenging activity of 85.12% when extracted for 2 h (Akin et al. 2013). Carvalho et al. (2010) reported the DPPH scavenging activity (EC50) of petroleum ether extract of green walnut husk to be 1.479 ± 0.117 mg/ml.

### 20.2.5 Leaves

Almeida et al. (2008) studied in detail the antioxidant activity of walnut leaf extracts against different pro-oxidant species. It was reported that $O_2\cdot^-$ scavenging activity was 47.6 ± 4.6 μg/ml, $H_2O_2$ scavenging activity was 383 ± 17 μg/ml, $^{\cdot}NO$ scavenging activity was 1.95 ± 0.29 μg/ml, and $ROO^{\cdot}$ scavenging activity was 2.17 ± 0.22 μmoles Trolox/extract concentration μg/ml. Another study on methanolic extracts of leaves on 14 different cultivars reported that the Trolox Equivalent Antioxidant Capacity of the extract ranged from 16.40 ± 0.41 mg Trolox/g FW in Jupanesti to 50.72 ± 0.44 in Fernor mg Trolox/g FW (Cosmulescu and Trandafir 2012). Akin et al. (2013) reported the radical scavenging activity of methanolic extracts of walnut leaves as 93.33% when extraction was done for 18 h. The DPPH scavenging activity ($EC_{50}$) of petroleum ether extract of walnut leaves was found to be 2.92 ± 0.74 mg/ml by Carvalho et al. (2010). The ORAC value for ethanolic extracts of walnut leaves reported by Wang et al. (2015) was 2543.50 ± 90.10 μmol TE/g, whereas the reducing power was 121.72 ± 5.18 μg/ml. This data also substantiates the evidence for use of walnut leaves in therapeutic use of leaves in inflammatory diseases.

### 20.2.6 Walnut Oil

Alasalvar and Shahidi (2009), reported that walnut oils exhibited the second highest antioxidant activity after pecan oils against ABTS (959.6 ± 21 mM of TE/g oil), DPPH (337.6 ± 27 α-TE/g oil), ORAC (3.41 ± 0.03 μmol α-TE/g oil), and PCL (μmol α-tocopherol/g oil). Gao et al. (2019) reported that the oxidative stability index of *Juglans sigillata* oil (2.19–3.46 h) to be less than that of *Juglans regia* oil (3.55–5.05 h). Amaral et al. (2003) studied the oxidative stability of six walnut cultivars grown in Portugal and reported that the oxidative stability ranged from 2.7 h in Parisienne to 3.4 h in Mayette.

## 20.3 Characterization of Antioxidants in Walnuts

Natural matrices are a source of antioxidative compounds like polyphenols, flavonoids, unsaturated fatty acids, etc. Walnuts, like other tree nuts, are rich in a variety of polyphenols, flavonoids, and tocopherols (Bolling et al. 2010). The antioxidant activity of different parts of walnut is shown in Table 20.3. The presence of phenolic compounds and exhibition of antiproliferative activity by walnut fruit extracts make them potential cancer chemo-preventive agent (Negi et al. 2011). Due to the high presence of phytochemicals, walnuts are potent anti-cholesterolemic, anti-inflammatory, hepatoprotective, and cardioprotective agents (Zibaeenezhad et al. 2017; Abdallah et al. 2015; Alexiadou and Katsilambros 2011; Papoutsi et al. 2008).

**Table 20.3** Antioxidant activity and content in different parts of walnuts (Jahanban-Esfahlan et al. 2019)

| | TPC (mg/g) DW | | TFC (mg/g) DW | | ORAC (μmol TEs/g extract) | FRAP (mmol $Fe^{2+}$/g DE) |
|---|---|---|---|---|---|---|
| | Minimum | Maximum | Minimum | Maximum | | |
| Kernel | 1.45 | 18.61 | 0.9 | 7.44 | 1481.21 | 522 (μM $Fe^{2+}$/g extract) |
| Skin | 52.05 | 279.3 | 0.5 | 10.96 | | |
| Shell | 18.04 | 18.04 | 4.86 | 4.86 | 3423.44 | 2202.29 |
| Husk | 6.27 | 36.1 | 0.7 | 12.22 | 2079.77 | 1220 |
| Leaf | 34 | 194 | 20 | 20 | 2543.5 | |

## 20.4 Nutrients as Antioxidants

### 20.4.1 Proteins

Proteins act as potent antioxidants through biologically designed mechanisms or by nonspecific mechanisms. Proteins inhibiting lipid oxidation by any of these mechanisms ultimately helps in contributing to the endogenous antioxidants magnitude of the foods. Antioxidant effect of proteins can be exhibited through a number of mechanisms like inactivating free radicals, scavenging action, chelating pro-oxidative transition metals, reducing hydroperoxides, and altering the physical properties of food systems (Elias et al. 2008).

Most of the walnut proteins are soluble in dilute NaOH (glutelin), other types include salt-soluble globulins, water-soluble albumin, and alcohol soluble prolamin (Ebrahimi et al. 2018). Walnuts contain 14.92 g protein per 100 g with abundant essential amino acids, like histidine (2.34 g/100 g protein), isoleucine (4.74 g/100 g protein), leucine (6.87 g/100 g protein), lysine (2.18 g/100 g protein), methionine (0.73 g/100 g protein), phenylalanine (4.41 g/100 g protein), threonine (3.08 g/100 g protein), tryptophan (1.04 g/100 g protein), and valine (5.78 g/100 g protein) (Longvah et al. 2017). Walnut contains 5.78 g valine per 100 g protein. Among nonessential amino acids, major amino acids are arginine (2.28 g/100 g), aspartic acid (1.83 g/100 g), glutamic acid (2.82 g/100 g), and serine (0.93 g/100 g) (USDA 2019). The range of amino acids (g/100 g protein) in 12 cultivars studied by Savage (2001) are aspartic acid (5.57–8.62), threonine (2.10–3.23), serine (3.31–5.11), glutamic acid (11.44–17.37), proline (2.26–3.42), glycine (3.11–4.74), alanine (2.42–3.57), valine (2.83–4.21), methionine (0.74–1.14), isoleucine (2.33–3.57), leucine (4.15–6.37), tyrosine (2.14–3.13), phenylalanine (2.89–4.08), histidine (1.59–2.39), lysine (2.01–2.91), and arginine (8.38–12.04). Walnut kernel contains high amount of alanine (Ebrahimi et al. 2018).

The amino acids like arginine, cysteine, histidine, leucine, lysine, tryptophan, valine, and their derivatives have high levels of antioxidant properties. It has been reported that peptides containing amino acids like histidine, tryptophan, and tyrosine possess distinct antioxidant capacity (Zhengjun et al. 2008). The enzymatic hydrolysates of Persian walnut (Chandler) seed proteins prepared using three proteases viz., pancreatic chymotrypsin, trypsin, and a microbial enzyme proteinase K, were found to possess antioxidant properties. These peptide fractions exhibited free radical scavenging activity against ABTS (Jahanbani et al. 2016). Chen et al. (2012) hydrolyzed walnut proteins using different proteases (neutrase, alcalase, and pepsin) and reported that the purified peptide showed 40.97 ± 2.74% DPPH radical scavenging activity, 31.01 ± 1.37% hydroxyl radical scavenging activity, and 36.34 ± 1.64% chelating activity, whereas the walnut protein peptides exhibited 2.06 ± 0.21% DPPH radical scavenging activity. The mechanism of action includes reacting of peptides with lipid radicals to reduce lipid peroxidation, inhibiting lipid peroxidation by increase in the lipid solubility of proteins, or due to metal chelation or electron donation (Wu et al. 2003; Ren et al. 2008; Chen et al. 2012).

### 20.4.2 Lipids

Lipids are usually auto-oxidative in nature but they may act as antioxidants due the presence of anti-oxygenic compounds like phytosterols and tocopherols. Usually fatty acids are susceptible to auto-oxidation, but long chain polyunsaturated fatty acids, when present at high concentration have been found to slow down auto-oxidation. Richard et al. (2008) investigated the indirect antioxidant potential of long chain fatty acids through human aortic endothelial cells. The fatty acids, previously dissolved in fetal calf serum were added to the cells, and the radical scavenging activity of the fatty acid micelles were noted as per cent inhibition compared to xanthine/xanthine oxidase. At the lowest concentration (1 μm), the highest activity was observed for eicosapentaenoic acid (59.5 ± 4.4%), followed by docosahexaenoic acid (46.9 ± 1.2%), oleic acid (25.3 ± 2%), linoleic acid (24.5 ± 3.8%), arachidonic acid (14.9 ± 3.8%), and stearic acid (10.3 ± 3.5%). In walnuts, apart from a higher concentration of omega-3 fatty acids, the presence of phospholipids, tocopherols, tannins, flavonoids, and phenolic acids can also inhibit auto-oxidation (Hayes et al. 2016).

The total fat content of walnuts (*Juglans regia* L.) is 65.78% (Li et al. 2017). Savage (2001) studied the composition of 12 cultivars of walnuts grown under same conditions and reported a lipid content in the range of 62.6 ± 0.27 g to 70.3 ± 0.17 g/100 g. Walnut seeds contain high amount of oil (52–70%) compared to other parts of walnut tree (Jahanban-Esfahlan et al. 2019). The major components of walnut lipid extracts are α-linoleic acid, α-linolenic acid, and oleic acid. By targeting cancer stem cells and inhibiting their self-renewal capacity, walnut lipid extracts have been found to have anticancerous properties (Chung et al. 2016). The content of total saturated fatty acids is 6.13 g/kg, of total monounsaturated fatty acids is 8.93 g/100 kg and of total polyunsaturated fatty acids is 47.17 g/kg (USDA database). As reviewed by Hayes et al. (2016), walnuts have more omega-3 fatty acids (14%) as compared to chestnuts (4.4%), almonds (1.2%), pistachios (0.7%), and peanuts (0.09%). Omega-6 fatty acids are also higher in walnuts (58.4%), as compared to chestnuts (34.7%), peanuts (31.6%), pistachio (29.7%), and almonds (23.3%), The important fatty acids present in walnuts are palmitic acid (3661 mg/100 g), stearic acid (1502 mg/100 g), oleic acid (11,168 mg/100 g), and linoleic acid (36,205 mg/100 g) (Gao et al. 2019; Longvah et al. 2017). Aryapak and Ziarati (2014) reported the presence of palmitic acid (6.1–6.4%), stearic acid (2.6–2.7%), oleic acid (21.9–25.3%), linoleic acid (51.4–53.2%), and linolenic acid (13.5–14.9%) in walnut oils from 12 cultivars in Iran. Palmitic acid (C16:0) is the major saturated fatty acid present in walnuts, which ranges 4.97–6.43% (Gao et al. 2019). A study reported that α-linolenic content of walnuts grown in New Zealand was 8.0–13.8%, whereas walnuts grown under same conditions in Italy had α-linolenic content of 12.8–15.3% (Savage et al. 2000). Abdallah et al. (2016) studied the composition of essential oil of Tunisian walnut from six cultivars viz., Franquette, Hartley, Local gd., Local pt., Lauzeronne, and Parisienne. The major classes of compounds identified were monoterpenes hydrocarbons (5.1–17.5%), sesquiterpene hydrocarbons (13.9–39.6%), sesquiterpene oxygenated (16.9–27.4%), alcohols (7.6–27.8%), and esters (0.3–1.1%). The compounds with highest concentration included β-caryophyllene (4.0–22.5%), and caryophyllene oxide (16.9–27.4%). From the seven walnut cultivars studied by Kafkas et al. (2017), Hartley variety was reported to have the linoleic (64.56%) and γ-tocopherol content (266.83 μg/g), and the highest linolenic acid content (13.26%) was reported in Howard variety. Unlike *Juglans regia*, *Juglans sigillata* (iron walnut) contains erucic acid (C22:1) in minor quantities, which can be a key component of iron walnuts (Gao et al. 2019).

### 20.4.3 Minerals

Elements exert an indirect antioxidant effect as they play an indispensable role as cofactors of various enzymes (Vural et al. 2010). Any alterations in their concentration, thus will affect the normal metabolic functioning of the enzyme systems. Zinc and selenium are nonenzymatic antioxidants (Carocho and Ferreira 2013). Walnuts are a good source of minerals like calcium (105 mg/100 g), copper (1.52 mg/100 g), iron 3.21(mg/100 g), magnesium (180 mg/100 g), manganese (3.47 mg/100 g), phosphorous (400 mg/100 g), potassium (457 mg/100 g), selenium (6.53 mg/100), and zinc (2.94 mg/100 g) (Longvah et al. 2017). Table 20.4 documents mineral content of walnut cultivars from different studies. Whole walnuts have a higher mineral content as compared to that of walnut oil as minerals are majorly bound with the proteins of the walnut kernel and remain with the residue upon pressing (Cindrić et al. 2018). These micronutrients are involved in antioxidant defense systems. Zinc stabilizes sulfhydryl groups of proteins and enzyme activity centers, thus playing defensive against oxidation. Zinc plays an important role in stimulation and activation of antioxidant enzymes glutathione and catalase (Bao et al. 2014). Of the major oxidative stress markers in human plasma are 8-hydroxydeoxyguanine, malondialdehyde, and 4-hydroxyalkenals. Zinc supplementation in healthy human adults have been found to lower the concentration of these stress markers in human plasma (Prasad 2014). Selenium incorporates into cysteine to form important

**Table 20.4** Content of major minerals with antioxidant capacity in different variety of walnuts

| Walnuts | Cultivars | Growing region | K | Ca | Mg | Mn | Fe | Cu | Zn | References |
|---|---|---|---|---|---|---|---|---|---|---|
| *Juglans Regia* | Sebin, Bilecik, Kaman 1 | Turkey | 359.7–398.2 | 149.32–202.26 | 126.95–165.15 | 3.97–4.79 | 3.27–3.68 | 1.54–1.57 | 2.94–3.48 | Yerlikaya et al. (2012) |
| *Juglans Regia* | Sebin type 1, Guvenli, Karabodur, Korcegor, Tozanlı | Turkey | 230–340 | 67–105.5 | 81–99 | 1.51–3.85 | 2.61–3.33 | 0.5–1.34 | 1.1–2.45 | Çağlarırmak (2003) |
| *Juglans Regia* | Valcor, valmit, valrex | Romania | 387.25–444.35 | 62.78–89.52 | 264.7–272.3 | 10.45–18.06 | 5.44–5.90 | 2.93–3.74 | 3.19–4.10 | Cosmulescu et al. (2009) |
| *Juglans Regia* | Chitral 1, SW-1, Chitral-2, SW-3, Dir-2 | Pakistan | 355.1–482.7 | 92.5–125.0 | 105.9–153.2 | – | 3.01–4.12 | 1.96–2.75 | 1.175–2.55 | Ali et al. (2010) |
| *Juglans Regia* | Chaboksar, Toyserkan, Karaj | Iran | 277–296 | 68.15–75 | 71–94 | 2.21–2.43 | 2.41–3.36 | 0.65–1.11 | 1.92–3.02 | Gharibzahedi et al. (2014) |
| *Juglans Regia* | Franquette, Hartley | France | 466–487 | 63–91 | 191–129 | 1.8–2.4 | 2.4–4.3 | 1.2–1.5 | 1.8–1.9 | Lavedrine et al. (1999) |
| *Juglans Regia* | Franquette, Hartley | California | 358–372 | 58–67 | 134–202 | 1.1–3.3 | 2.3–2.9 | 1.1–1.4 | 1.2–1.6 | Lavedrine et al. (1999) |
| *Juglans Regia* | Serr, Hartley, Chandler, Howard | Spain | 300–370 | 83–135 | 381–443 | 2.03–2.44 | 1.5–2.1 | 0.72–1.49 | 1.76–1.95 | Tapia et al. (2013) |
| *Juglans nigra* | Tetracarpidium conophorum | Africa | 24.08 | 44.99 | 59.77 | 3.2 | 2.89 | 1.87 | 6.78 | Chijioke et al. (2015) |
| *Juglans sigillata* | Y021, Y026, Y041, Y042, Y075, Y082, Y096, Y098, Y099, Y101 | China | – | 155.10–318.6 | 538.4–771.93 | 9.35–24.51 | 9.71–13.72 | 3.65–6.91 | 7.66–11.56 | Zhai et al. (2014) |

antioxidant enzyme systems, called selenoproteins, which also constitute five form of glutathione peroxidases apart from the thioredoxin and other enzymes (Fairweather-Tait et al. 2011; Weeks et al. 2012). A positive relationship between lower concentration of selenoproteins and reduced ability of the body to fight ROS has been established through in vitro cell culture studies (Gresner et al. 2009; Cooper et al. 2008; Baliga et al. 2007). One of the important roles of selenium is inhibition of oxidative damage of DNA and RNA (Zuo et al. 2006). Selenium also inhibits lipid peroxidation along with Vitamin E (Salmonowicz et al. 2014). Manganese is the cofactor in the mitochondrial antioxidant manganese superoxide dismutase. Similarly, copper ions are the cofactor in Cu–Zn-superoxide dismutase. Copper ions are antioxidants at low concentrations, whereby these are capable of binding iron ions to transferrin, thus preventing ROS (superoxide radicals, hydroxyl radicals, and hydrogen peroxide) generation (Johnson et al. 1992). Copper also possess pro-oxidative properties (Lobo et al. 2010), but human physiological process prevents the accumulation of copper ions in our body through regulation of absorption and excretion and thus prevents copper to act as a pro-oxidant (Johnson et al. 1992). Magnesium is involved in the synthesis of glutathione. It has been observed that magnesium deficiency results in a twofold reduction of glutathione concentration in erythrocytes (Zheltova et al. 2016).

### 20.4.4 Vitamins

Both Vitamin C and Vitamin E are nonenzymatic antioxidants. As per the Indian Food Composition Tables, 100 g of walnuts have 1.59 μg of Vitamin A, 13.05 Mg/100 g biotin, 0.88 Mg/100 g Vitamin C, 57.95 Mg/100 g total folates, and 4.12 α-tocopherol equivalent (Vitamin E) (Longvah et al. 2017). At normal concentrations, Vitamin C reduces ROS to form stable ascorbate free radicals that are single electron donors. The free ascorbate radicals either (1) further reduced to ascorbate through reductase enzymes, or (2) combine with each other to form a molecule each of ascorbate and DHA (Grosso et al. 2013). However, at lower concentrations, Vitamin C acts as a pro-oxidant when it reacts with $Fe^{3+}$ to reduce it to $Fe^{2+}$, or when it reacts with $Cu^{3+}$ to reduce it to $Cu^{2+}$ (Carocho and Ferreira 2013; Lü et al. 2010). $Fe^{2+}$ or $Cu^{2+}$ can further reduce hydrogen peroxide to free hydroxyl radicals (Lü et al. 2010; Duarte and Lunec 2005). On the other hand, due to the presence of four -OH groups, ascorbic acid can donate hydrogen, chelate metal ions, or scavenge free radicals (Brewer 2011). The tocopheroxyl radical can also be reduced by ascorbic acid during the lipid peroxidation chain reaction. The ascorbyl radical thus generated can be reduced by glutathione-dependent enzymes – dehydroascorbate and peroxidase (Traber and Stevens 2011). A positive relationship between ascorbic acid deficiency and oxidative stress in clinical trials also substantiate the evidence of Vitamin C as an important antioxidant (Harrison et al. 2010; Harrison and May 2009; Tveden-Nyborg and Lykkesfeldt 2009). Vitamin E has been discussed under the subhead tocopherols.

## 20.5 Non-nutritive Antioxidants

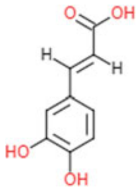
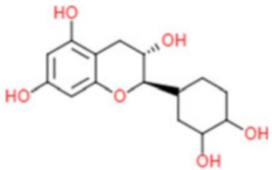
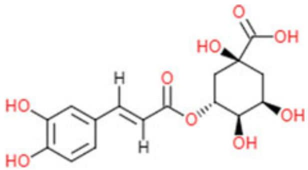
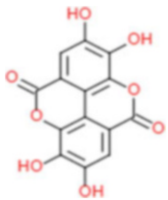
In general, all plant-derived chemicals are termed as phytochemicals. All macronutrients, micronutrients, and non-nutrients can therefore be categorized as phytochemicals. For current usage, we will use this term for non-nutrients with beneficial biological effects.

### 20.5.1 Polyphenols

"Poly" refers to more than one. A molecule with more than one phenolic group is termed as polyphenol. Polyphenols, the biggest group of phytochemicals, are secondary plant metabolites involved in defense against ultraviolet radiation and contributing toward oxidative stability (Pandey and Rizvi 2009). Phenolic compounds, the enzymatic antioxidants, are the major plant defense mechanisms fighting against stresses like environmental, pathogenic, or other injuries (Jahanban-Esfahlan et al. 2019; Carocho and Ferreira 2013; Lü et al. 2010). Polyphenols, also referred to as chain-breakers, neutralize free radicals by donating and electron, disrupting the chain oxidation reactions, and becoming stable themselves (Tsao 2010; Clifford 2000). Due to their antioxidant properties, they have also been inversely associated with chronic disease conditions like cancer, diabetes, cardiovascular diseases, hepatic diseases, DNA oxidative damage, etc. Polyphenols have been also found to function as co-antioxidants involved in the generation of essential vitamins, and in metal chelation (Tsao 2010). Polyphenols can induce several antioxidant enzymes. These include catalase that decompose hydrogen peroxide ions, peroxidase that decompose hydroperoxide ions and superoxide that decompose superoxide anions (Du et al. 2007). Another mechanism of action studied in in vivo experiments show synergism between protein-binding action of polyphenols and antioxidant activity. When polyphenols are present at specific LDL sites prone to oxidation, they inhibit the oxidation reaction and prevent LDL damage (Wang and Goodman 1999). A series of redox-dependent reactions are triggered when polyphenols interact with enzymes involved in signal transduction and resultant modification of redox status (Scalbert et al. 2005). Table 20.5 lists the important phytochemicals found in walnuts along with their biological properties.

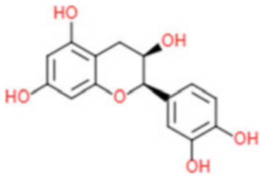
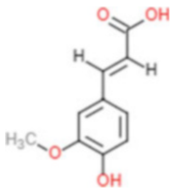
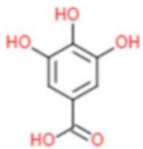
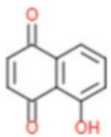
Walnuts has the third highest (1156 mg GAE/100 mg) total phenolic content among the major nine tree nuts, viz. almonds, brazil nuts, cashew nuts, hazelnuts, macadamias, pecans, pine nuts, pistachios, and walnuts (USDA database). The phenolic acid content of walnuts is 36 mg/100 g, which is the highest among nuts (Alasalvar and Bolling 2015). The total phenol content of 11 walnut varieties studied by Pycia et al. (2019), ranged from 0.82 to 2.09 g GAE/100 g dm. Different parts of the walnut tree have been reported to contain total phenolic contents as kernel (145–15,540 mg/100 g estimated average), shell (1804–2300 mg/100 g estimated average), husk (3428.11 mg/100 g), leaves (2136 mg/100 g), bark (3483 mg/100 g), and pellicle (5205 mg/100 g) (Ebrahimi et al. 2018). Another study by Arcan and Yemenicioğlu (2009) reported that the aqueous and ethanolic extracts of fresh

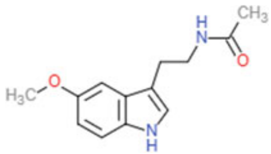
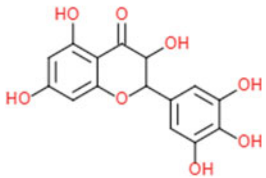
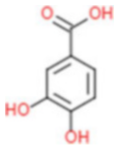
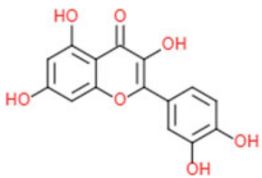
**Table 20.5** Phytochemicals present in walnuts and their biological properties

| Compound | Structure | Molecular formula | Biological activities | References |
|---|---|---|---|---|
| Caffeic acid |  | $C_9H_8O_4$ | Anti-inflammatory, antineoplastic, antioxidant, inhibits cancer cell proliferation | Pycia et al. (2019), Anjum et al. (2017) and Nour et al. (2012) |
| Catechin |  | $C_{15}H_{14}O_6$ | Antioxidant | Jahanban-Esfahlan et al. (2019), Nour et al. (2012), Stampar et al. (2006) and Mira et al. (2002) |
| Chlorogenic acid |  | $C_{16}H_{18}O_9$ | Anticancerous, anti-inflammatory, antioxidant, neuroprotective | Anjum et al. (2017) and Nour et al. (2012) |
| Ellagic acid |  | $C_{14}H_6O_8$ | Anticancerous, anti-oxidant, anti-proliferative | Anjum et al. (2017), Nour et al. (2012) and Stampar et al. (2006) |

(continued)

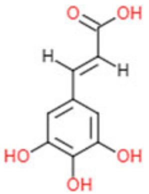
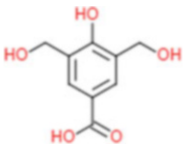
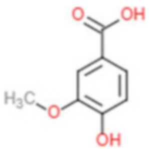
**Table 20.5** (continued)

| Compound | Structure | Molecular formula | Biological activities | References |
|---|---|---|---|---|
| Epicatechin |  | $C_{15}H_{14}O_6$ | Anti-inflammatory, antioxidant | Nour et al. (2012) |
| Ferulic acid |  | $C_{10}H_{10}O_4$ | Anticoagulant, anti-inflammatory, antihypertensive, antioxidant, cardioprotective, nonsteroidal agent | Pycia et al. (2019), Anjum et al. (2017) and Nour et al. (2012) |
| Gallic acid |  | $C_7H_6O_5$ | Antiangiogenic, antifungal, anti-inflammatory, antimicrobial, hepatoprotective | Pycia et al. (2019), Anjum et al. (2017) and Nour et al. (2012) |
| Juglone |  | $C_{10}H_6O_3$ | Antibacterial, antitumor | Jahanban-Esfahlan et al. (2019), Oliveira et al. (2008), Mahoney et al. (2000) and Radix et al. (1994) |

| | | | | |
|---|---|---|---|---|
| Melatonin |  | $C_{13}H_{16}N_2O_2$ | Antioxidant | Bolling et al. (2011) |
| Myricetin |  | $C_{15}H_{10}O_8$ | Antineoplastic, antioxidant, cyclooxygenase 1 inhibitor, acetylcholinesterase inhibitor, cardioprotective, hepatoprotective, hypoglycemic | Jahanban-Esfahlan et al. (2019), Nour et al. (2012) and Mira et al. (2002) |
| Protocatechuic acid |  | $C_7H_6O_4$ | Ameliorative, chemopreventive, antihypertensive, antioxidant, anti-inflammatory, antimicrobial | Pycia et al. (2019) and Stampar et al. (2006) |
| Quercetin |  | $C_{15}H_{10}O_7$ | Anticancer, antifungal, antioxidant | Jahanban-Esfahlan et al. (2019), Vieira et al. (2019), Nour et al. (2012) and Mira et al. (2002) |

(continued)

**Table 20.5** (continued)

| Compound | Structure | Molecular formula | Biological activities | References |
|---|---|---|---|---|
| Sinapic acid |  | $C_{11}H_{12}O_5$ | Antioxidant | Pycia et al. (2019), Anjum et al. (2017) and Nour et al. (2012) |
| Syringic acid |  | $C_9H_{10}O_5$ | Anticatalytic, antifungal, antioxidant, antiatherogenic | Jahanban-Esfahlan et al. (2019), Pycia et al. (2019), Anjum et al. (2017) and Nour et al. (2012) |
| Vanillic acid |  | $C_8H_8O_4$ | Anti-inflammatory, specifically inhibits 5′nucleotidase activity | Pycia et al. (2019), Anjum et al. (2017) and Nour et al. (2012) |

walnuts have a phenolic content of 515 ± 21 and 240 ± 13 mgGAE/100 g DW respectively.

Vieira et al. (2019) characterized phenolics composition of *Juglans regia* leaves at green and yellow stages and reported a total phenolic acid content of 16.7 ± 0.2 and 5.9 ± 0.1 mg/g extract respectively. The most abundant phenolic acid was reported to be trans 3-p-coumaroylquinic acid in both kind of leaves. In the same study, the content of total phenolic compounds was reported as 29.7 ± 0.03 mg/g and 23.26 ± 0.06 mg/g extract for green and yellow leaves, respectively. Nour et al. (2012) and Anjum et al. (2017) identified the following free phenolics in walnut leaves: chlorogenic acid, caffeic acid, ellagic acid, ferulic acid, gallic acid, vanillic acid, syringic acid, p-coumaric acid, sinapic acid, salicylic acid, and trans-cinnamic acid. Stampar et al. (2006) reported same phenolics in walnut husks. Juglone, syringic, and ellagic acid have 20 times higher concentration in seed coat as compared to walnut seed alone (Jahanban-Esfahlan et al. 2019). Higher concentration of polyphenols in seed coat is to protect the seed as polyphenols as a defense mechanism of plants.

Anderson et al. (2001) used walnut polyphenolic heat and cold extracts to investigate their antioxidant potential in in vitro human plasma. Plasma was isolated from blood of five healthy individuals, and it was found that the heat extracts inhibited oxidation by 23% and 31% at a concentration of 100 and 150 μmol/L GAE, respectively. The cold extracts inhibited oxidation by 28% and 35% at a concentration of 100 and 150 μmol/L GAE, respectively.

### 20.5.2 Flavonoids

A subclass of polyphenols, flavonoids are characterized by a chalcone structure ($C_6C_3C_6$). Flavonoids can scavenge free superoxide anion, singlet oxygen, reactive nitrogen and chlorine species, peroxy radicals, or by forming compounds with oxidizing species (Halliwell 2008; Birt et al. 2001). Majorly, flavonoids are electron donors and form conjugated ring structures, which are relatively inactive (Hudson and Lewis 1983). Flavonoids have demonstrated ability to prevent cell proliferation and angiogenesis in vitro by hindering the cell cycle at G1/S and G2/M (Virgili and Marino 2008; Birt et al. 2001). Flavonoids can also form complexes with copper and iron, and thus prevents free radical generation (Nimse and Pal 2015).

Pycia et al. (2019), in their study on 11 *Juglans regia* varieties, identified gallic acid, protocatechuic acid, syringic acid, 4-coumaric acid, gentisic acid, vanillic acid, caffeic acid, di-hydro-*p*-coumaric acid, ferulic acid, sinapic acid, 3-coumaric acid, 3,4,8,9,10-pentahydroxydibenzo[b,d]pyran-6-one, and carboxylic derivatives of syringic acid. Extract of green peels and leaves of walnuts are reported to contain flavonoids which exhibit hypoglycemic properties (Javidanpour et al. 2012; Pereira et al. 2007).

Total flavonoid content in green and yellow leaves of *Juglans regia* was reported to be 13.0 ± 0.2 and 17.4 ± 0.2 mg/g extract, respectively, with the most abundant yield of quercetin-3-O-glucoside (Vieira et al. 2019). Nour et al. (2012) identified the following flavonoids in walnut leaves: catechin, epicatechin, myricetin, quercetin, and rutin. Stampar et al. (2006) identified protocatechuic acid in walnut husks, in addition to the ones identified by Nour et al. (2012). Quercetin, catechin, and myricetin are also found in walnut shoots (Jahanban-Esfahlan et al. 2019). Hydrojuglone β-d-glucopyranoside, found in walnut shoots, is a glucose derivative of juglone (Jahanban-Esfahlan et al. 2019). The $Fe^{3+}$ ions–reducing activity (μmoles $Fe^{2+}$/μmole flavonoids) is in the order – myricetin (1.2), quercetin (1.0), rutin (0.2), and catechin (0.2), whereas $Cu^{2+}$-reducing activity (μmoles $Cu^{+}$/μmole flavonoids) is in the order myricetin (12.5), quercetin (9.2), rutin (8.6), and catechin (9.4) (Mira et al. 2002).

### 20.5.3 Alkaloids

Alkaloids biologically active nitrogen containing compounds formed as products of microbial, plant, and animal origin. Alkaloids are different from other nitrogenous compounds like protein, nucleic acids, antibiotics, etc. Melatonin and juglone (7–19 mg/100 g), a naphthoquinone, are the major alkaloids present in walnuts (Bolling et al. 2011).

Melatonin is also named as a terminal antioxidant due to its ability to form many stable end-products on being oxidized (Lobo et al. 2010). A single melatonin molecule can scavenge up to 10 ROS or NOS in both in vivo and in vitro conditions unlike other common antioxidants and its antioxidant activity has been found to be superior to that of glutathione, NADH, vitamin C, and vitamin E (Manchester et al. 2015; Tan et al. 2015). Manchester et al. (2015) carried out a detailed review on antioxidant activities on melatonin. Melatonin and its metabolites, viz. cyclic 3-hydroxymelatonin (c3OHM), N1-acetyl-5-methoxykynuramine (AMK), and N (1)-acetyl-N(2)-formyl-5-methoxykynuramine (AFMK) can detoxify superoxide anion radical, singlet oxygen species, hydrogen peroxide, hydroxyl radicals, nitric oxide, peroxynitrite anion, peroxyl radical, alkoxyl radical, and hypochlorous acid (Manchester et al. 2015). Manda et al. (2007) investigated the effect of AFMK-treated mice exposed to X-ray-induced oxidative damage and reported that AFMK was an important •OH scavenger and inhibited the radiation-induced lowering of sulfhydryl and total antioxidant capacity. AFMK at a low concentration of 338.08 nM, reduced the formation of DMPO (5,5-dimethyl-1-pyrroline N-oxide) •OH radicals by 50%; beyond 500 nM concentration, 100% scavenging of •OH radicals was found.

The major compound present in green walnut husk and walnut shoot is juglone ($C_{10}H_6O_3$) (5-hydroxy-1,4-napthoquinone) (Jahanban-Esfahlan et al. 2019; Oliveira et al. 2008). Juglone, earlier named nucin, from the Latin *nux*, meaning nut, is the main phenolic compound which has an active role in walnut defense mechanism (Mahoney et al. 2000; Radix et al. 1994). The in vitro study of Juglone on human cancer cell line has established its anticancer activity. Blocking the S-phase of the cell cycle, activating mitogen-activated protein kinases, or inducing mitochondrial-dependent apoptosis pathways in gastric cells, leukemia cells, and ovarian cells have been reported as the mechanism for anticancer activity of Juglone (Ahmad and Suzuki 2019). Reese et al. (2010) investigated the effect of Juglone on unilateral ureteral obstruction model of rats to study the mechanism of fibrogenesis, and reported that Juglone reduced oxidative stress.

### 20.5.4 Phytosterols

Phytosterols is a term used for lipophilic plant–synthesized steroids. Yoshida and Niki (2003) reported the antioxidant effect of β-sitosterol, campesterol, and stigmasterol, against 2,2,5,7,8-pentamethyl-6-chromanol. β-sitosterol has been found to scavenge ROS and to stimulate antioxidant enzymes mediated by estrogen receptor and PI3-kinase activation (Vivancos and Moreno 2005). Phytosterols, in optimal quantities have been found to exert anti-cholesterolemic effects by either precipitating with cholesterol or competing with cholesterol transporters, or by competing for space in mixed micelles, thereby reducing cholesterol absorption (Brufau et al. 2008; Trautwein et al. 2003). Since mixed micelles also contain lipid-soluble antioxidant vitamins, the phytosterols, at a higher concentration, can also displace them along with cholesterol (Brufau et al. 2008). Low doses of phytosterols (0.8–4.0 g/day) can reduce LDL concentrations by 10–15%.The fat soluble bioactives of walnut oil include tocols (43.72 mg/100 g), phytosterols (307 mg/100 g), and sphingolipids (290 mg/100 g) (Alasalvar and Bolling 2015). Among phytosterols, β-sitosterol is the major phytosterol reported in walnuts. Of total phytosterol dietary intake more than 95% is contributed by β-sitosterol, campesterol, and stigmasterol. Abdallah et al. (2015) studied six varieties of *Juglans regia* L., and reported the total sterol content as follows: 1525 $\pm$ 0.51 mg/kg in Franquette, 1401 $\pm$ 15.56 mg/kg in Hartley, 1489 $\pm$ 3.26 mg/kg in Local gd., 1144 $\pm$ 1.51 mg/kg in Local pt., 1222 $\pm$ 2.71 mg/kg in Lauzeronne, and 1679 $\pm$ 28.3 mg/kg in Parisienne. The β-sitosterol content of these varieties was 89.26%, 87.70%, 69.42%, 85.17%, 88.48%, and 89.03% in the same order. The campesterol content of these varieties was 5.13%, 4.84%, 0.33%, 4.02%, 4.79%, and 5.24% in the same order.

Vu et al. (2019) conducted a study on six black walnuts, viz., Emma K, Kwik Krop, Mystry, Schessler, Sparks 147, and Tomboy, and compared it with the English walnuts (*Juglans regia* L.). The study identified 13 phytosterols in the black walnut (*Juglans nigra* L.) kernels, viz. campesterol, stigmasterol, $\Delta^{5,23}$-stigmastadieenol, clerosterol, β-sitosterol, stigmastanol, Δ5-avenasterol, $\Delta^{5,24(25)}$-stigmastadiene, cycloeucalenol, cycloartenol, 28-methylobtusifoliol, 24-methylenecycloartenol, and citrostadienol. The β-sitosterol content of English walnut (*Juglans regia* L.) (1007.2 $\pm$ 35.7 mg/kg of kernels), was less compared to the other six black walnut kernels except mystery variety (988.3 $\pm$ 68.7 mg/kg kernels). The Schessler variety of black walnut kernels had the maximum content (1223.9 $\pm$ 84.3 mg/kg kernels) of β-sitosterol. On the other hand, the campesterol content was found to be highest in English walnut kernels (49.5 $\pm$ 3.0 mg/kg of kernels) as compared to the black walnut kernels (31.9 ± 2.4 mg/kg of kernels in Kwik Kop variety to 47.7 ± 0.9 mg/kg of kernels in Schessler variety).

### 20.5.5 Tocopherols

Vitamin E is the main antioxidant in lipoproteins. Vitamin E, the fat-soluble vitamin, is a collective term used for tocopherols and tocotrienols. Lipid peroxidation reactions produce lipid peroxy radicals (LOO˙). Tocopherols, in both in vitro and in vivo systems, have been found to stabilize these radicals, terminating the chain reaction and forming relatively stable tocopheroxyl radicals (Nimse and Pal 2015; Lobo et al. 2010). The content of α-tocopherol in walnuts is lesser than that of other nuts (Jahanban-Esfahlan et al. 2019).

Kafkas et al. (2017) studied the tocopherol and total phenols profile of many cultivars of walnuts, viz., Bilecik, Chandler, Hartley, Howard, Maras 12, Maras 18, Midland, Pedro, Sen and Serr, and reported a total tocopherol content of 2370–3490 mgGAE/100 g extract. Among the tocopherol analogues, α-tocopherols content was 28.61–35.17 μg/g, γ-tocopherol + β-tocopherol was 161.07–312.19 μg/g, δ-tocopherol was 17.35–40.77 μg/g. Abdallah et al. (2015) reported a total tocopherol content of 186.54–283.11 mg/kg in six walnut varieties (listed earlier in lipids section). The values of tocopherol analogues reported in this study were as follows – α-tocopherol (1.93–12.81 mg/kg), β-tocopherol (0.31–0.57 mg/kg), γ-tocopherol (162.54–358.95 mg/kg), and δ-tocopherol (16.76–44.73 mg/kg). Another study carried out by Pycia et al. (2019) on 11 varieties of *Juglans regia* reported a total tocopherol content of 19.83–126.0 mg/kg. The concentration of tocopherol analogues reported in this study was as follows – α-tocopherol (1.7–14.2%) and γ-tocopherol (10.7–35.3%). Total tocopherol content reported by Li et al. (2007) was 307.98 ± 2.5 μg/g in Combe Persian walnut and 222.15 ± 3.95 μg/g in Lake Persian walnut. Here also, the γ-tocopherol content was highest (267.87 ± 1.95 μg/g in Combe Persian walnut and 205.45 ± 2.72 μg/g in Lake Persian walnut), followed by δ-tocopherol content (31.79 ± 0.51 μg/g in Combe Persian walnut and 11.64 ± 0.30 μg/g in Lake Persian walnut).

The total tocopherol content of *Juglans sigillata* oil ranges from 394.74 to 403.44 mg/kg, whereas that of *Juglans regia* oil is 441.03–490.32 mg/kg (Gao et al. 2019). Among the four homologues of tocopherols (α, β, γ and δ), the γ tocopherols were present in highest quantities in both *Juglans sigillata* and *Juglans regia* oils (222.10–271.34 mg/kg and 289.33–345.40 mg/kg, respectively).

## 20.6 Health Benefits of Walnuts

Antioxidants present in walnut are associated with several health-promoting effects. Clinical investigations have shown association between walnut consumption and lower risk of different lifestyle diseases such as CVD, diabetes, obesity, cancer, etc.

This section contains brief information regarding major health benefits associated with walnuts.

### 20.6.1 Ageing

Impact of walnut on the ageing process has been studied recently. It is known to delay the process of ageing by controlling telomere shortening. A randomized clinical trial on "Walnuts and Healthy Aging" was conducted on 708 participants with the mean age 69 years, 68% women. On supplying 15% of the daily energy intake from walnuts for 2 consecutive years, delay in the onset of age-related cognitive impairment and retinal pathology was observed. On similar intake, reduced telomere shortening was observed to be responsible for delayed ageing by Freitas-Simoes et al. (2018).

### 20.6.2 Obesity

Walnut is reported to have antiobesity effect due to its reported association with weight loss and weight management. Antiobesity effect of walnut is attributed to its rich PUFA content, polyphenols, and proteins (Table 20.6). Proposed mechanisms underlying include the ability of walnuts to control hunger as well as induce satiation and satiety; thereby controlling overall energy intake (Rock et al. 2017b; Katz et al. 2012). Presence of fatty acids and proteins induce the secretion of CCK and glucagon like peptide 1 (GLP-1) in the gut. These hormones are responsible for delayed gastric emptying and reduced meal frequency. Longer chain fatty acids with greater degree of unsaturation are known to influence the satiating impact of fatty acids (Lutz and Luna 2016).

Another mechanism reported for antiobesity effects of walnut is by modification of intestinal microflora. The two major phyla, namely Bacteroidetes and Firmicutes, comprise of the normal human gut microbiota. Increase in the number of Firmicutes on the cost of Bacteroidetes has been reported in obese populations (Selma et al. 2016). Walnut kernel husk is believed to regulate intestinal bacteria by increasing the relative population of Bacteroidetes over Firmicutes. The husk specifically decreases the abundance of bacteria like *Fusobacteria*, *Romboutsia*, *Lachnoclostridium*, and *Peptostreptococcaceae* (Wang et al. 2019). This helps in decreasing overall body weight gain and fat accumulation. A randomized control trial on elderly (average age 69 years) with 67% women was conducted. Walnuts were supplemented up to 15% daily needs in case population, while control group was abstained from walnuts. The result showed that the consumption of walnut with the normal food intake does not promote any gain in weight (Bitok et al. 2018). Similar results were obtained by Katz et al. (2012) in a randomized controlled crossover trial on 46 overweight adults (mean age 57.4 years). The result of the investigation revealed that daily consumption of 56 g of walnuts improves endothelial function in obese adults with visceral adiposity.

**Table 20.6** The Role of walnut in different health conditions

| Health disorder | Design of study | Sample size/study group | Intervention | Mode of action | Compound identified for action | Outcomes | References |
|---|---|---|---|---|---|---|---|
| Aging | Randomized control trial | 149/cognitively healthy elders (63–79 years old) | Walnut supplementation (15% of energy) for 24 months | Preservation of leukocyte telomere length | Omega 3 fatty acids | | Freitas-Simoes et al. (2018) |
| Cognitive dysfunction caused by aging | D-galactose-induced amnesic model | 50/d-galactose-induced aging mice | Orally gauged with (a) walnut seed (600 mg/kg) (b) seed coat (100 mg/kg) | Inhibition of AChE activity | Polyphenols and unsaturated fatty acids | Seed coat more effective in reducing oxidative damage and limits neuroinflammation | Liu et al. (2019) |
| Cognitive function and retinal health on ageing | Blind, randomized 2-year clinical trial | 708/mean age 69 years, 68% women | 15% of energy (≈30–60 g/day) | – | – | Delaying the onset of age-related cognitive impairment and retinal pathology | Rajaram et al. (2017) |
| Weight reduction | Randomized control trial | 100/non-diabetic overweight and obese men and women | 15% of energy (≈30–60 g/day) | Reduction in plasma gamma-tocopherol | Tocopherol and polyunsaturated fatty acid | Reduced body weight, body mass index and waist circumference | Rock et al. (2017a) |
| Weight reduction | Crossover study design | 28/overweight/obese adults | ~54% of energy from walnuts | Induction of early satiety | Polyunsaturated fatty acid | Weight control | Rock et al. (2017b) |
| Hyperlipidemia | Double-blind, placebo-controlled, randomized trial | 100/hyperlipidemic type 2 diabetic patients aged 35–75 years | 15 cc Persian walnut oil or placebo every day for 90 days | Facilitation in receptor-mediated LDL clearance by hepatocytes | Polyunsaturated fatty acid | Significant decrease in total cholesterol levels increase in HDL (TD = 2.28, $P = 0.06$) LDL level below 100 in 20% cases | Zibaeenezhad et al. (2017) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Diabetes | Randomized control trial | Streptozotocin induced diabetic rats | 6%, 9%, and 12% walnut for 6 weeks | | Polyunsaturated fatty acid | No significant effect on blood glucose | Ghorbani et al. (2014) |
| Diabetes | Cross-sectional, probability survey | 34,121/aged from 0 to 85 years | – | Decreased feelings of hunger | Polyunsaturated fatty acid | Lower risk for diabetes (odds ratio of 0.47, 95% [CI] 0.31–0.72) and fasting blood glucose (relative risk ratio 0.32, CI 0.17–0.58) and HbA1c (relative risk ratio 0.51, CI 0.27–0.99). 47% less diabetes reported with each standard deviation increase. | Arab et al. (2018) |
| Cardiovascular disease | Parallel-group, multicenter, randomized trial | 425/males (55–80 years) and females (60–80 years) with no CVD at enrollment | 15 g of walnuts with other nuts | | Polyphenols and unsaturated fatty acids | Reduction in CVD (myocardial events infarction, stroke, or death infarction, stroke) | Estruch et al. (2018) |
| Cardiovascular disease | Randomized, controlled, postprandial, 4-period crossover study | 15/Healthy overweight and obese adults (n = 15) with moderate hypercholesterolemia | 85 g ground, whole walnuts; 34 g ground, skinless, defatted nut meat from walnuts; 51 g oil from skinless | | Polyphenols and unsaturated fatty acids | Oxidative stress (FRAP assay) significantly greater in comparison to the nut-meat group (P, 0.01). The nut | Berryman et al. (2013) |

(continued)

**Table 20.6** (continued)

| Health disorder | Design of study | Sample size/study group | Intervention | Mode of action | Compound identified for action | Outcomes | References |
|---|---|---|---|---|---|---|---|
| | | | walnuts; or 5.6 g ground walnut skins | | | meat tended to lower mean FRAP from baseline | |
| Cardiovascular disease | Randomized control, 3 diet, 3 period, crossover study | 20/ hypercholesterolemic subjects | 37 g and 15 g of walnuts and walnut oil, respectively, per day | Improvement in plasma lipids and endothelial function | Omega 3 fatty acids | Decrease in diastolic blood pressure 2–3 mm Hg total cholesterol significantly reduced by 4% | West et al. (2012) |
| Cancer | Genomic analysis | Human renal cancer cell lines A-498 and 769-P, and the colon cancer cell line Caco-2 | 31.25, 62.5, 125, 250, and 500 μg extract/mL | | Specific phytochemicals may be responsible for antiproliferative action | Inhibition in the growth of cancer cells in dose-dependent manner No correlation with total phenol content was observed | Carvalho et al. (2012) |
| Prostate cancer | Genomic analysis | LNCaP (androgen responsive) human prostate adenocarcinoma cell line | 40 μM urolithin A | Increase in G1-phase, induction of apoptosis and caspases 3 and 7 | Pedunculagin | Chemopreventive agent for prostate cancer | Sánchez-González et al. (2016) |

### 20.6.3 Diabetes

Literature on clinical trials conducted have mixed results regarding the association of walnut consumption in controlling blood glucose levels. National Health and Nutrition Examination Survey (NHANES) study depicts that walnut consumption lowers risk of diabetes compared with non-nut consumers. Reduced levels of HbA1c (glycated hemoglobin: form of hemoglobin that is covalently bound to glucose) across all walnut consumers were also observed. Similarly, fasting blood glucose concentrations were also found to be lowered among walnut consumers (Arab et al. 2018). It has been demonstrated through randomized trial that inclusion of walnuts in the diets of type 2 diabetes mellitus (T2DM) risk group of adults led to the lower risk of developing T2DM and improved the overall diet quality. Inclusion of 56 g of walnuts in the daily for 6 months. An increase in the intake of total fat, calcium, magnesium, thiamin, total saturated fatty acids, MUFA, and PUFA was found on inclusion of 56 g of walnuts in the daily diet for 6 months (Njike et al. 2015).

Proposed mechanism underlying the antidiabetic activity includes inhibition of enzymes α-glucosidase and α-amylase. The consumption of ethanolic extract of internal septum of walnut tor 28 days significantly helped in reducing the blood sugar levels in alloxan-induced diabetic rats (Rahimi et al. 2011). The impact is attributed to higher content of polyphenols ($21.65 \pm 1.44$ mg GAE/g), which have been found to inhibit the activity of α-glucosidase and α-amylase (Ghiravani et al. 2016).

Another mechanism proposed is the ability of walnuts to modify micro-RNAs. A significant modification in common miRNA of plasma were observed on inclusion of walnuts and almonds in a normo-caloric diet at a rate of 15 g/day for 8 weeks. Increase in circulating PUFAs correlated with modifications in plasma miR-106a. Plasma micro-RNAs have been associated with changes in C-reactive protein, plasma fasting triglycerides, and adiponectin, thereby affecting blood glucose levels (Ortega et al. 2015). Walnuts are rich in polyphenol ellagitannins. Urolithins A and B derived from walnut ellagitannins improved fasting insulin levels and insulin sensitivity at significant levels (Espín et al. 2013).

An alteration in the lipoprotein lipid profiles and enhancement in their ability to reduce TNFα-dependent pro-inflammatory responses in human diabetic primary adipocytes has been reported on consumption of walnuts. When hypercholesterolemic, postmenopausal females were fed on 40 g/day of walnuts for 4 weeks; an increase in the levels of α-linolenic acid and its epoxides was observed in all lipoproteins when 40 g/day of walnuts were fed to the hypercholesterolemic postmenopausal females for 4 weeks. A decrease in the TNF-α-induced diabetic adipocyte production of IL-6 ($-48\%$, $P = 0.0006$) and IL-8 ($-30\%$, $P = 0.01$) is also reported for walnut consumption (Borkowski et al. 2019). Therefore, it can be concluded that the moderate consumption of walnut can alter lipoprotein and lipid profile.

### 20.6.4 Cardiovascular Diseases

High content of ALA in walnuts is linked with its cardioprotective effects. Several epidemiological studies have associated walnut consumption with positive impact on health indices like reduced cholesterol levels, high HDL, low LDL, etc. The content of PUFA in walnuts is related to better receptor-mediated LDL clearance by liver cells (Zibaeenezhad et al. 2017). In the study conducted by Ghiravani et al. (2016), it has been found that walnut septum ethanolic extract not only showed antihyperglycemic effect, but also observed that a dosage of 200 mg/kg can significantly lower LDL and triglyceride levels after 28 days of oral administration.

Antihypertensive effect of walnuts has also been seen due to higher content of calcium, potassium, magnesium, fatty acids, and polyphenols. Potassium modulates renin–angiotensin mechanism, and reduced peripheral resistance. Calcium on the other hand inhibits parathormone, thereby reducing blood pressure. Due to the presence of polyphenols, walnuts have protective effect on dexamethasone-induced hypertension (Joukar et al. 2017).

English walnut intake has been associated with positive impact on plasma lipids levels and plaque formation in atherosclerosis. A study conducted using proatherogenic ApoE mice model analyzed the effect of feeding of high fat diet with the supplementation of English walnuts, walnut oil to the control group for the period of 8 weeks. It was reported in this study that a 55% reduction in the atherosclerotic plaque formation was found walnuts in aortic arch on feeding of whole walnuts as compared to the control group. However, no such result was found on feeding walnut oil. Further a decrease in the levels of triglycerides (36%), cholesterol (23%), and prothrombin serum (21%) was found in the first group. A combination of n-3 PUFA along with polyphenols was attributed for the atheroprotective effect of English walnuts (Nergiz-Ünal et al. 2013).

### 20.6.5 Cancer

Walnuts have been known to have anticancerous effect on human beings, due to the presence of high polyphenol content. Several studies have demonstrated that daily intake of walnuts can have constructive impact against oxidative stress–mediated diseases like cancer (Carvalho et al. 2010). The major polyphenols found in walnut, pedunculagin and ellagitannin, have demonstrated potent antioxidant and anti-inflammatory bioactivity. Role of ellagitannins further contributes to limit initiation and progression of many diseases, including cancer. On entering the human body, ellagitannins are hydrolyzed to release ellagic acid, which is later changed to urolithin A and its derivatives (B, C, and D) by gut microbiota (Sánchez-González et al. 2016).

Fatty acids present in walnut have also been reported to have anticancer activity. Walnut oil consumption induces necrosis and arrest cell cycle at $G_0/G_1$ phase which exhibit anticancer effect. A high-dose, short-term administration of walnut oil has been reported to suppress NFkB pathway and decrease cell viability and metastatic ability of esophageal cancer cells (Batirel et al. 2018). These studies indicate that the consumption of walnut and walnut oil may have beneficial effects in esophageal cancer in humans.

## 20.7 Conclusion

The optimum blend of nutrients in walnuts explains the enormous health benefits associated with walnuts. These contain good quantity and quality of fat, proteins, fiber minerals, and numerous bioactive components. The antioxidant properties of walnuts are attributed to different phytochemicals present in walnuts. The phytochemicals are broadly divided into nutritive and non-nutritive compounds broadly in this chapter. Nutritive phytochemicals possessing antioxidant behavior include lipids with high amount of PUFAs – linoleic and linolenic acid, proteins with amino acids acting as antioxidants, minerals like manganese, magnesium, etc. The fiber content is high in walnuts which contribute to its lipid-lowering effects. Walnuts enclose 10% of their energy as ALA. Non-nutritive compounds of significance present in walnut include phytomelatonin, ellagitannins, and more polyphenols and flavonoids than any other kind of nut. This differential composition showcases walnuts to be in a category of special nuts and contribute to several health benefits. Health benefits associated with walnuts include their effectiveness against various health conditions like aging, diabetes, obesity, cardiovascular diseases, cancers, neurological disorders, etc. Inclusion of walnuts in diet can serve as an important intervention against multiple, rising adverse health conditions. The benefits of walnuts are not achieved through single nutrient but rather is a result of the functional synergy of the bioactive components enclosed in a complex matrix acting at various metabolic and physiological levels in human body.

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# Almond

# 21

Antima Gupta, Rajan Sharma, and Savita Sharma

**Abstract**

Almond (*Prunus dulcis*) is a drupe, belongs to *Rosaceae* family, ranked one in the production of tree nut worldwide, majorly from the United States (~80%). Typically, five major varieties are grown in United States, which include Mission, Nonpareil, California, Peerless and Neplus Ultra. There are four major portions: hull, shell, brown leathery skin and kernel. The edible kernel is majorly utilized as snack or as an ingredient in bakery and confectionary products and by-products are fed to livestock. Nuts are rich in protein, lipid, dietary fibre, vitamins and minerals. Besides almond, kernel also encompasses bioactive compounds like phenolic compounds, tocopherols, sterols and resveratrol. Many researchers identified that by-products of almond processing industry are the potential source of anti-disease or phytochemicals, especially brown leathery skin of almond (~95%). These bioactive compounds possess antioxidant activity with potential to decrease the oxidative DNA damage and lipid oxidation leading to the prevention of degenerative diseases like coronary heart diseases (CHD), cholesterol lowering, diabetes and cancer. Therefore, almond and its by-products can potentially be utilized as an alternative to synthetic chemical or as dietary supplement or as a functional food ingredient in the development of convenience or nutraceutical food.

**Keywords**

Almond · Coronary heart diseases · Phenolic compounds · Tocopherols · Sterols · Resveratrol

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## 21.1 Botanical Name, Common Name

Almonds are known as "pseudo nut" because they are edible seed of a drupe. They belong to the genus *Prunus* of family *Rosaceae* and order *Rosales*. This family includes ~2950 species of 91 genera (Christenhusz and Byng 2016; Zhang et al. 2019) and it is known as one of the major families of angiosperm. Based on fruit type, *Rosaceae* family is divided into four sub-families: *Amygdaloideae*, *Maloideae*, *Rosoideae* and *Prunoideae* (Potter et al. 2007). *Prunus* belongs to the sub family *Amygdaloideae,* and consists of approximately 430 species with most species growing in temperate zone of the northern hemisphere and only few in tropical and subtropical regions (Chen et al. 2013; Zhang et al. 2019). Figure 21.1 represents the botanical classification of almond. *Prunus* genera are the most economical among all, since many species are source of fruits like almond, plum, apricot,

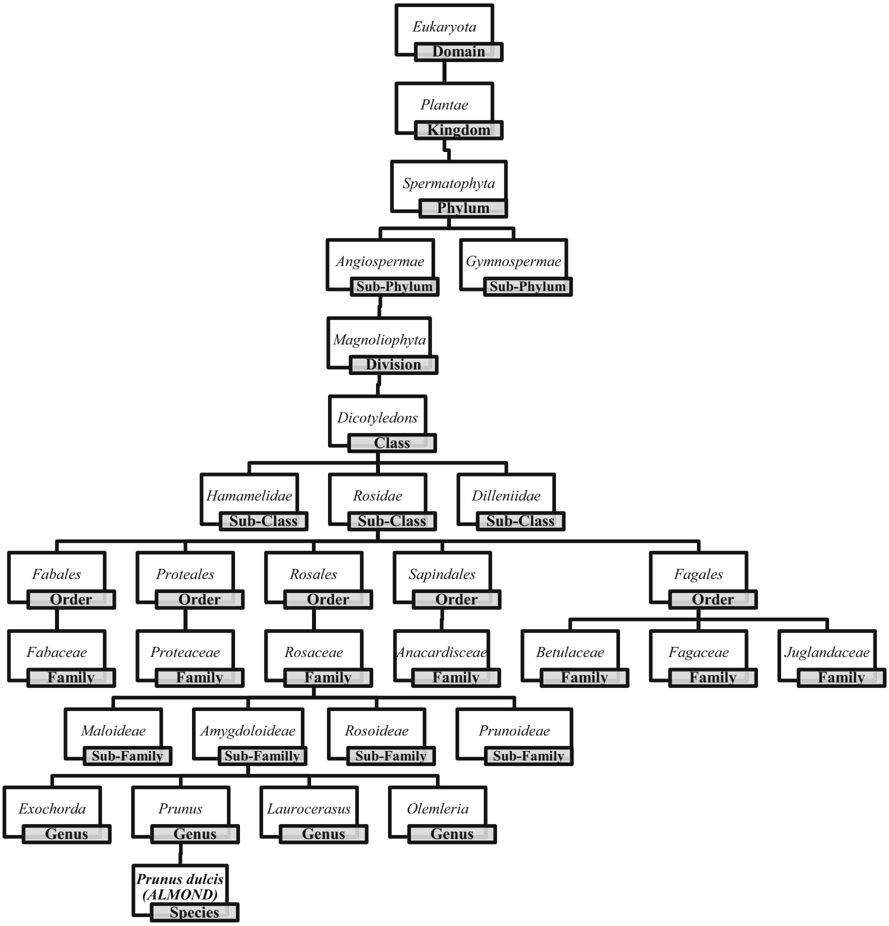


**Fig. 21.1** Botanical classification of almond

cherries and peaches. Classification of *Prunus* genera into subgenera is always a highly controversial topic due to continuous evaluation of morphological characters. Tournefort (1700) categorized *Prunus* into six sub-genera, *Armeniaca, Amygdalus, Cerasus, Laurocerasus, Prunus and Persica,* whilst Linnaeus (1753) divided them into four, *Armeniaca, Cerasus, Padus and Prunus.* Later researchers revised Linnaeus classification into five to eight genera (Miller 1754; Hutchinson 1964; Yu et al. 1986). Till date, it is not clear how many sub-genera are under *Prunus*. *Prunus dulcis* is a scientific name of almond and alternative words includes *Prunus communis* L. and *Prunus amygdalus* Batsch (Kester et al. 1991).

Internationally almond is known by different common names like English: Almond; USA: Almond; Germany: Mandel, Mandelbaum; Italy: Mandorlo; Spanish: Almendro; French: Amande, Amandier; Chinese: Badanmu, Biantao, Borden xing, Xinren shu; Portuguese: Amendoeira; Brazil: Amendoeira-doce; Denmark: Mandeltrae; Poland: Migdalek; India: Badam and many more. Due to diversity in Indian culture, languages, and religion, almond is popular with different names like Badam in Sanskrit, Bilaiti Badam in Bengali, Badami in Kanada, Vadumai in Tamil, Badamu in Telugu, Badam Shireen in Urdu and Lauzul Hulu in Arabic.

## 21.2 Introduction

Almond is one of the most well-known tree nuts grown on a worldwide basis and is ranked one in the production compared to other nuts. Almond belongs to *Rosaceae* family that includes peach, pear plum, apple, apricot, berries and prunes. These fruits have stony endocarp thereby, also popularly known as stone fruits. The United States is the major producer of almonds accounting 80% of the total world production, followed by Spain, Iran, Morocco and Turkey. In the United States, almond majorly comes from California. Regularly, 5 varieties are majorly grown in the United States which include Mission, Nonpareil, California, Peerless and Neplus Ultra (Sang et al. 2002a, b). Almond contains four major portions: Hull or mesocarp, Shell or endocarp, a thin brown leathery skin on kernel and kernel (Fig. 21.2). The edible part of the almond is kernel, used with or without skin as per the requirement. They are usually consumed as snacks, as ingredient in bakery and confectionary items (Sang et al. 2002a, b).

Almond is considered as nutritionally dense nut comprising protein and lipid as a major nutrients. Lipids accounting 50% of the kernel weigh with major proportion of mono-unsaturated fatty acids (MUFA) (32.2%) followed by poly-unsaturated fatty acid (PUFA) (12.2%) and very less of saturated fatty acids (3.9%).On the other hand, protein varied between 16% and 22% of the almond weight and all the amino acids present are bound to amandin protein of almond. Moreover, dietary fibre content ranges from 10.8% to 13.5% of the kernel weight including, cellulose, lignin, pectin and xyloglucans. Almonds comprise vitamins, mainly fat-soluble and minerals like Ca, K, Mg, Na, P, Fe, Zn, Se and Mn (Yada et al. 2011). Besides, almond also consists of bioactive compounds like phenolic acids, flavonoids, sterol, tocopherols and resveratrol. These compounds have antioxidant activity that neutralize or

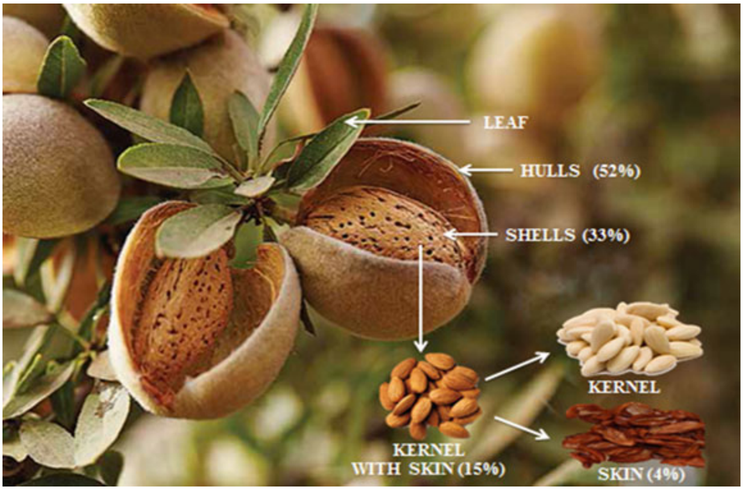


**Fig. 21.2** Different parts of almonds

inhibits oxidation by reducing oxygen concentration, scavenging initial radicals and metal chelating agents, capturing singlet oxygen, converting primary products to non-reactive compounds and breaking chain of continuous removal of free radicals from the substrate (Yuan and Kitts 1996). Compounds possessing antioxidant activity not only vary with type of nut and its species but also from the location, harvest year, processing and storage.

Earlier studies revealed antioxidants as the best source to reduce oxidative stress in the biological system, thus preventing degenerative diseases like coronary heart diseases (CHD), lowering blood cholesterol, diabetes, cancer and hypertension. Studies reported that the presence of MUFA, protein, dietary fibre and phytosterols in almonds lowers the LDL-cholesterol in the human body, thereby reducing the chances of atherosclerosis and ultimately CHD (Hyson et al. 2002; Penny et al. 2008; Richardson et al. 2009; Ortiz et al. 2012; Kamil and Chen 2012; Berryman et al. 2015). Regarding cancer, several researchers reported that the presence of high-profile phenolic compounds in almonds prevents oxidative DNA damage and lipid oxidation, and reduces the risk of cancer (Soriano et al. 2015; Lee et al. 2017, 2018). Almonds have low glycaemic index due to the presence of high dietary fibre and low carbohydrate, and thus possess gluco regulation effect in the body (Li et al. 2010; Kamil and Chen 2012; Gulati et al. 2017; Hou et al. 2018). Apart from that, it helps in weight management, immunity boosting, anti-ageing and hepatic protection. This chapter reviews botanical description, production, antioxidant compounds present in almond, their characterization, mechanism of biological activities and their beneficial health effect.

### 21.2.1 History

Almond is one amongst the well-known tree nuts in Western diets primarily due to the nutritional quality of the almond kernel. Almond trees are native of central and south-western Asia particularly Iran and surrounding countries. In the course of early civilization, almonds and other crops including olives, figs, grapes, etc. were bought to the Mediterranean region, particularly Spain, Italy and Morocco, through major trade routes. This boom of almond lasted long years till the early colonists settled in America. These were further brought to California in the late nineteenth century and cultivated under similar climatic conditions as that of the Mediterranean. In the late twentieth century, almonds were globally disseminated successfully at industrial scale (Janick and Paull 2008). In the beginning of twenty-first century, California almond industry faced a lot of competition from South Australian almond industries. Now, California State of the United States is one of the major producers of almond worldwide. Typically, 5 major varieties are grown in California, which includes Mission, Nonpareil, California, Peerless and Neplus Ultra (Sang et al. 2002a, b). From the five listed varieties, the first three contribute to 90% of the production coming from California (Esfahlan et al. 2010).

### 21.2.2 Production (India, World)

World total production of almond reached 3,182,902 tonnes in 2018; an increase of 495,092 tonnes from the year 2017 was observed by FAO in 2018. The United States ranked one with the total production of 1,872,500 tonnes, followed by Spain (339,033 tonnes), Iran (139,029 tonnes), Morocco (117,270 tonnes) and Turkey (100,000 tonnes) (FAOSTAT 2018). Besides kernel, almond shells of about 0.8–-1.7 million tonnes (Pirayesh and Khazaeian 2012) and hulls of about six million tonnes (Takeoka et al. 2000) are produced from the almond-processing industry as a by-product which are either discarded or fed to livestock. From the National Horticulture Board (NHB) 2018, production of almond in India is majorly from Kashmir and Himachal Pradesh, with a major share from Kashmir (94.45%) than Himachal (5.55%).

### 21.2.3 Botanical Description and Processing

The almond tree is a small deciduous plant growing 4–10 meter tall, with trunk diameter of up to 30 cm. Almond plant can grow in arid regions due to its resistance to drought conditions (Prgomet et al. 2017). Almond trees are not promptly productive and bear fruit after 5 years, and after 7–8 months of flowering in the autumn season, fruits become mature (Griffiths and Anthony 1992) In botanical term, almond is a drupe of 3.5–6.0-cm long with a thick green-brown hull that indicates exocarp and mesocarp portions with an average weight of 52%. Creamish brown woody shell represents endocarp with a kernel inside known as endosperm (33%).

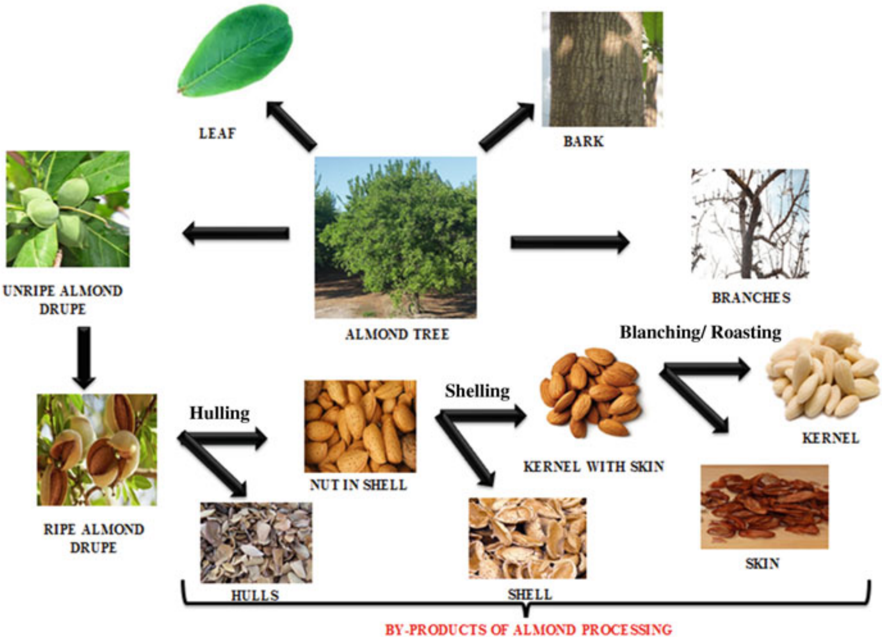


**Fig. 21.3** Overview of almond and its processing

Along with hulls and shells, during almond processing, two more by-products are obtained, that is, skin and blanch water (Fig. 21.3). In the earlier days, these by-products were sent as cattle feed. But in the recent past, by seeing the potential of these by-products being rich in phytochemicals, they are suggested as a potential alternative for natural antioxidants, which can be recovered and utilized further as preservatives and dietary supplements.

## 21.3 Antioxidant Properties

Oxidation is a process in which transfer of electron takes place from one compound to another, causing physiological damage. In biological system, oxidation occurs by free radical mechanism and causes oxidative stress in the body due to which chances of degenerative disease increase. Several studies recognized that consumption of antioxidants effectively reduces the oxidative stress in the cell. Antioxidants are the compounds that inhibit or delay oxidation of compounds. Due to the paradigm shift from synthetic to natural source for antioxidants, almonds, being rich in antioxidants, can play a potential role in combating degenerative diseases. Table 21.1 is presenting the antioxidant compounds present in different parts of almonds.

**Table 21.1** Antioxidant compounds identified in almond, its products and by-products

| S. no. | Almond part | Antioxidant compound present | Radical scavenging activity | Reference |
|---|---|---|---|---|
| 1 | Leaves, stems bark and roots | Protocatechuic acid, catechin, 2-prenylated benzoic acid, 2-prenyl-4-*O*-*β*-D-glucopyranosyl-oxy-4-hydroxybenzoic acid, and prenylated benzoic acid | – | Siriwardhana and Shahidi (2002) |
| 2 | Leaves and stem bark | *Leaf*: Total flavonoid (7.80 mg QUE/g); Total phenol (62.50 mg GAE/g); Gallic acid (64.23 mg/g), catechin (25.18 mg/g), chlorogenic acid (53.47 mg/g), caffeic acid (46.15 mg/g), ellagic acid (98.82 mg/g), epicatechin (21.82 mg/g), rutin (45.06 mg/g), quercitrin (79.65 mg/g), isoquercitrin (52.03 mg/g), quercetin (26.71 mg/g), kaempferol (65.13 mg/g) | Leaf: 0.17 mmolTEAC/g for ABTS radical; 0.49 mg/mL for DPPH radical | Sunday et al. (2017) |
| | | *Stem bark*: Total flavonoid (3.44 mg QUE/g); Total phenol (37.30 mg GAE/g); Gallic acid (1.05 mg/g), catechin (1.78 mg/g), caffeic acid (6.93 mg/g), ellagic acid (5.85 mg/g), rutin (1.06 mg/g) quercetin (3.45 mg/g), kaempferol (1.76 mg/g), resveratrol (5.91 mg/g) | Steam bark: 0.09 mmolTEAC/g for ABTS radical; 0.57 mg/mL for DPPH radical | |
| 3 | Hulls | Red variety: Tannins (0.55 mg/100 g); Flavonoids (1.24 mg/100g); Phenols (0.17 mg/100g); Alkaloids (1.45 mg/100 g) | Red variety: 18.30–48.50% | Okudu et al. (2017) |
| | | Yellow variety: Tannins (0.61 mg/100 g); Flavonoids (1.29 mg/100g); Phenols (0.18 mg/100g); Alkaloids (1.38 mg/100 g) | Yellow variety: 16.70–43.80% | |

(continued)

**Table 21.1** (continued)

| S. no. | Almond part | Antioxidant compound present | Radical scavenging activity | Reference |
|---|---|---|---|---|
| 4 | Hulls | Betulinic acid (40.9%), oleanolic acid (15.6%) and ursolic acid (43.5%) | – | Takeoka et al. (2000) |
| 5 | Hulls | Total phenolic content: 398 mg GAE/g extract; Total flavonoid content (mg Quercetin/g) | 16.3 mg $FeSO_4$, 74.8% DPPH radical and 0.651 reducing power | Safarian et al. (2016) |
| 6 | Hulls | 5-*O*-caffeoylquinic acid (chlorogenic acid), 3-*O*-caffeoylquinic acid (neochlorogenic acid), caffeoylquinic acid (cryptochlorogenic acid), sterols, stigma sterols, sitosterol | – | Takeoka and Dao (2003) |
| 7 | Shell | Total phenolic compounds: 3.422 mgGAE/g | 94.40% radical scavenging activity for DPPH | Thebo et al. (2012) |
| 8 | Shell | Total phenolic compound: 71 mg quercetin/g; Free phenolic acids: 13.99 μg/g: Total esterified phenolic acid: 967.10 mg/g | – | Wijeratne et al. (2006a) |
| 9 | Skin/ bran | Flavonoids and phenolic acids like Procatechuic acid (1541.67 μg/100 g), 5-Hydroxy-benzoic acid (6401.2 μg/100 g), catechin (15,569 μg/100 g), Vanillic acid (5805.23 μg/100 g), Epicatechin (10955.64 μg/100 g), trans-p-Coumaric acid (367.71 μg/100 g), eriodictyol-7-*O*-glucoside (3382.47 μg/100 g), Quercetin-3-*O*-rutinoside (3197.65 μg/100 g), Quercetin-3-*O*-galactoside (1339.65 μg/100 g), Quercetin-3-glucoside (896.45 μg/100 g), eriodictyol (470.09 μg/100 g), Naringenin (20634.38 μg/100 g), | 8.33 μg GAE/0.24 mg of skin (DPPH) | Mandalari et al. (2010) |

(continued)

**Table 21.1** (continued)

| S. no. | Almond part | Antioxidant compound present | Radical scavenging activity | Reference |
|---|---|---|---|---|
| | | Kaempferol (1249.97 μg/100 g), Isorhamnetin (4551.85 μg/100 g). | | |
| 10 | Skin | Flavonol glycosides, quercetin, kaempferol, naringenin, flavanone glycoside, catechin, protocatechuic acid, vanillic acid, p-hydroxybenzoic acid, α-tocopherol | – | Sang et al. (2002a, b) |
| 11 | Skin | Total phenolic compound: 88 mg quercetin/g; free phenolic acids: 16.28 μg/g, total esterified phenolic acid: 279.55 mg/g | – | Wijeratne et al. (2006a) |
| 12 | Skin | Total phenolic content 3.6% | – | Chen et al. (2005) |
| | | catechin (186.9 nmol/g), epicatechin (77.5 nmol/g), isorhamnetin (20.8 nmol/g), quercetin (6 nmol/g), kaempferol (3.9 nmol/g) | | |
| 13 | Skin | Catechin (35.7%), procatechuic acid (17.6%), epicatechin (33.9%), p-hydroxybenzoic acid (17.5%), vanillic acid (18.2%), quercetin-3-*O*-galactoside (41.4%), naringenin-7-*O*-glucoside (16.1%), quercetin-3-*O*-rutinoside (43.7%), quercetin-3-*O*-glucoside (24.5%), dihydroxykaempferol (50.8%), kaempferol-3-*O*-galactoside (34.6%), isorhamnetin-3-*O*-galactoside (35.0%), kaempferol-3-*O*-glucoside (39.0%), kaempferol-3-*O*-rutinoside (40.4%), isorhamnetin-3-*O*-rutinoside (28.5%), | – | Milbury et al. (2006) |

(continued)

**Table 21.1** (continued)

| S. no. | Almond part | Antioxidant compound present | Radical scavenging activity | Reference |
|---|---|---|---|---|
| | | eridictyol (48.7%), naringenin (34.1%), kaempferol (100%), quercetin (100), isorhamnetin (47.2%) | | |
| 14 | Kernel | Kaempferol (223.54 μg/g); Naringenin (5.01 μg/g); Vanillic acid (110.89 μg/g); Caffeic acid (65.72 μg/g); Ferulic acid (16.49 μg/g); δ-Tocopherol (3.05 mg/kg); α-Tocopherol (104.40 mg/kg) | 87.30% (DPPH) | Serhat et al. (2014) |
| 15 | Kernel | α-Tocopherol (25.9 mg/100 g); γ-Tocopherol (0.9 mg/100g); Flavonoid (15.25 mg/100g); Flavan-3-ols (4.47 mg/100g); Flavanones (0.38 mg/100g); Flavonols (7.93 mg/100g); Anthocyanins (2.46 mg/100 g); Isoflavones (0.01 mg/100 g) | – | Kornsteiner et al. (2006), USDA (2009) and Bradley et al. (2010) |
| 16 | Kernel | Total Phenolics: 0.32 to 3.47 mg GAE/g and Total Flavonoids: 1.61 to 2.82 mg CE/g in different almond cultivars | 0.78 to 2.21 μg Trolox/g (DDPH), 1.29 to 19.24 μg Trolox/g (ABTS) and 1.88–9.16 μg Trolox/g (FRAP) in different cultivar | Oliveira et al. (2018) |
| 17 | Kernel | Total phenolic compound: 8 mg quercetin/g; Trace amount of free phenolics, Total esterified phenolic acid: 40.34 mg/g | – | Wijeratne et al. (2006a) |
| 18 | Kernel | Catechin (8.8%), procatechuic acid (12.2%), epicatechin (4.0%), vanillic acid (9.3%), naringenin-7-*O*-glucoside (10.5%), kaempferol-3-O-galactoside (20.1%), isorhamnetin-3-*O*- | – | Milbury et al. (2006) |

(continued)

**Table 21.1** (continued)

| S. no. | Almond part | Antioxidant compound present | Radical scavenging activity | Reference |
|---|---|---|---|---|
| | | galactoside (3.2%), kaempferol-3-O-glucoside (16.6%), kaempferol-3-*O*-rutinoside (7.0%), isorhamnetin-3-*O*-rutinoside (2.9%), naringenin (28.1%), isorhamnetin (2.1%) | | |
| 19 | Almond oil | Campesterol (2.46 mg/kg), campestanol (0.13 mg/kg), stigmasterol (0.91 mg/kg), Δ7-campesterol (0.78 mg/kg), β-sitosterol (77.42 mg/kg), sitostanol (1.91 mg/kg), Δ5-avenasterol (9.89 mg/kg), Δ5,24-stigmastadienol (1.48 mg/kg), Δ7-stigmasterol (1.94 mg/kg), Δ7-avenasterol (1.39 mg/kg), squalene (96.43 mg/kg), phytol (71.65 mg/kg), geranylgeraniol (28.35 mg/kg), α-tocopherol (233.40 mg/kg), β-tocopherol (8.45 mg/kg), γ-tocopherol (10.10 mg/kg) and δ-tocopherol (0.87 mg/kg) | – | Fernandes et al. (2017) |
| 20 | Almond oil | Hydraulic pressed oil: Total phenolic content-18.8 mg caffeic acid/kg, cholesterol (0.2%), brassicasterol (0.1%), campesterol (3%), stigmasterol (1%), Δ7-stigmasterol (0.30%), β-sitosterol (95%), erythrodiol + uvaol (0.1%). | – | |
| | | Screw pressed oil: Total phenolic content-22.8 mg caffeic acid/kg, | | |

(continued)

**Table 21.1** (continued)

| S. no. | Almond part | Antioxidant compound present | Radical scavenging activity | Reference |
|---|---|---|---|---|
| | | cholesterol (0.1%), brassicasterol (0.1%), campesterol (3.2%), stigmasterol (1.30%), Δ7-stigmasterol (0.3%), β-sitosterol (95%), erythrodiol + uvaol (0.1%). | | |

### 21.3.1 Almond Leaves and Stem Bark

Almond leaves and bark are attributed to the presence of polyphenols like protocatechuic acid, catechin, prenylated benzoic acid, 2-prenylated benzoic and 2-prenyl-4-*O*-*β*-D-glucopyranosyl-oxy-4-hydroxybenzoic acid (Wijeratne and Siriwardhana 2002). Almond leaves and bark extract have a higher percentage of phenolic compounds with noteworthy cardioprotective activity. Phenolic compounds like catechin, epicatechin, gallic acid, ellagic acid, chlorogenic acid, caffeic acid, rutin, quercetin, quercitrin, isoquercitrin, kaempferol and resveratrol have antioxidative and antihypertensive properties (Sunday et al. 2017).

### 21.3.2 Hull

Hulls or mesocarp are the shell cover of almonds that are dry, leathery and astringent to the taste during harvesting. Astringency is characterized because of the presence of flavonoid in the hulls. Flavonoids present in the hulls play a major role against oxidative stress and stable senescence period, leading to the synthesis of lignin's in hulls. Besides, hulls also contain insoluble fibre like pectin, hemicellulose, cellulose, and tannin-like complex polyphenols. Earlier, hulls were the major by-products from almond-processing industries, mainly utilized as a cattle feed. In recent times, hulls are gaining attention and utilized as a natural source of sweetener, dietary fibre, triterpenoids and phenolics (Esfahlan et al. 2010).

Hulls possess very good antioxidant properties; many researchers reported the presence of phenolic compounds like caffeic acid (in traces), ferulic acid (2.71 μg/g), sinapic acid (9.92 μg/g), crytochlorogenic acid (7.9 mg/100 g), neochlorogenic acid (3.04 mg/100 g), trans-p-coumaric acid (1.34 μg/g), protocatechuic acid, catechin, quercetin, kaempferol-3-*O*-rutinoside/glucoside, isorhamnetin, isorhamnetin-3-*O*-glucoside and morin (Sang et al. 2002a, b; Wijeratne et al. 2006a, b).

Okudu et al. (2017) reports the presence of total flavonoid, phenols, tannins, alkaloid content in hulls of red and yellow variety of almond fruit. Radical scavenging activity for DPPH varied between 18.30% and 48.50% and between 16.70% and

43.80%, for red and yellow variety, respectively. Safarian et al. (2016) reported the presence of total phenolic and flavonoids with a radical scavenging activity of 16.3 mg $FeSO_4$ and 74.8% of DPPH radical. Almond hulls contain three major triterpenoids (~1%) such as betulinic acid, oleanolic acid and ursolic acid that act as anti-cancer, anti-inflammatory and anti-HIV agents (Takeoka et al. 2000). On the other hand, they are a rich source of phenolics like catechin, benzoic acid, protocatechuic acid and 4-hydroxybenzoic acid. It has been estimated that about six million tons of hulls are produced per year and used as a livestock feed, but being rich in antioxidant compounds, these hulls can be utilized to make value-added products.

Takeoka and Dao (2003) isolated dietary antioxidants such as caffeoylquinic acid, 3-*O*-caffeoylquinic acid, 5-*O*-caffeoylquinic acid, sterols, stigma sterols, sitosterol from hulls.

### 21.3.3 Shell

Shell is the ligneous matter (endocarp) covering almond kernel. Almond kernel is the recovered by-product from almond industries. Being rich in xylan, it makes them a suitable substrate for xylose, furfural or for fraction into cellulose, lignin and pentosans (Pou-Ilinas et al. 1990; Martinez et al. 1995; Quesada et al. 2002; Esfahlan et al. 2010). Cellulose, lignin and pentosans can be further acid hydrolysed to recover hemicellulose and liquid phase contains sugar, acetic acid, derivatives of lignin and sugar dehydration product, which can be further utilized to produce oxyaromatic compound, and which finds application in food and cosmetic (Quesada et al. 2002). Thebo et al. (2012) noticed remarkable antioxidant capacity of 94.40% for DPPH radical in woody almond shells due to the presence of phenolic compounds (3.422 mgGAE/g) that are known for its high antioxidant properties.

Wijeratne et al. (2006a, b) reported 63% more total phenolic compound in almond shell in comparison to almond kernel, whilst 17% less total phenolic than the skin of the kernel. They also reported that hydrophobic phenolics are three times more than the hydrophillic in almond shell. Phenolic compounds present in shells are sinapic acid, caffeic acid, p-coumaric acid, ferulic acid and hydroxycinnamic acid. Moreover, almond shells also contain triterpenoid, flavonoids, and phenolic acids with excellent radical scavenging properties (Siriwardhana and Shahidi 2002).

### 21.3.4 Skin

The brown leathery skin surrounding almond kernel is playing a major role in protecting kernel from microbial attack and oxidation. Sometimes, kernel is required without skin for the development of products, so from those processing units, almond skin is collected as a by-product, which is a major source of antioxidant compound. Almond skin constitutes 4–8% in weight of the total shelled almond. Antioxidant compounds present in skin depend upon the removal process In 2008, Garrido and co-workers suggested roasting as the most effect method of skin removal followed by blanching and oven drying.

Several studies reported the presence of bioactive compounds in almond skin such as sinapic acid (9.51 μg/g), caffeic acid (in traces), ferulic acid (2.19 μg/g), vanillic acid (11.1–19.2 μg/g), chlorogenic acid (1.76–3.77 μg/g), trans-p-coumaric acid (4.55 μg/g), p-hydroxybenzoic acid (3.08–7.18 μg/g), protocatechuic acid (6.69–17.2 μg/g), catechin (36.40–90.10 μg/g), epicatechin (14.8–36.6 μg/g), quercetin (1.02–4.89 μg/g), quercetin-3-*O*-glucoside (1.33–2.41 μg/g), quercetin-3-*O*-galactoside (41.4%), quercetin-3-*O*-rhamnoside, kaempferol (2.75–12.1 μg/g), kaempferol-3-*O*-rutinoside (12.8–31.80 μg/g), kaempferol-3-*O*-glucoside (14.2 μg/g), isorhamnetin (5.90–16.0 μg/g), isorhamnetin-3-*O*-rutinoside (27.60–41.40 μg/g), isorhamnetin-3-*O*-glucoside (8.85–15.60 μg/g), morin, naringenin (6.84–22.10), eriodictyol (0.808–1.60 μg/g) in almond skin (Monagas et al. 2007; Garrido et al. 2008; Arraez-Roman et al. 2010). It is known to be the richest source of polyphenolic compounds in comparison to leaves, stembark, roots, hull, shell and kernel. Sang et al. (2002a, b) isolated vanillic, quercetin, catechin, protocatechuic acid and p-hydroxybenzoic acid from almond skin. Isorhamnetin, isorhamnetin 3-*O*-glucoside, Kaempferol 3-*O*-rutinoside, quercetin, quercitrin and morin are the major flavonoids present in almond skin (Wijeratne et al. 2006a, b).

Though almond skin only comprises 4–8% of almond weight, still around 95% of flavonoids are present in almond skin (Milbury et al. 2006). Also, almond skins contain more phenolic compounds like procatechuic acid, p-hydroxy-benzoic acid, catechin, vanillic acid, epicatechin, p-hydroxy benzaldehyde, vanillin, trans-p-coumaric acid, trans-ferulic acid, 5,5′-Diferulate and 8,5′-diferulate (benzofuran form) and flavonoids like quercetin-3-*O*-rutinoside, quercetin-3-*O*-galactoside, quercetin-3-glucosise, eriodictyol, naringenin, kaempferol, isorhamnetin (Mandalari et al. 2010). Mekala et al. (2017) observed scavenging of 542.28 mg DPPH radical, 359.72 mg of nitric oxide radical and 35.54 mg of phosphomolybdinum radical, and this was attributed to the presence of polyphenols, flavonoids like flavonols, flavan-3-ols, flavanones, tannins and hydroxybenzoic acid. Frison-Norrie and Sporns (2002) isolated four flavonol glycoside-isorhamnetin glucoside, isorhamnetin rutinoside, kaempferol glucoside and kaempferol rutinoside from almond skin. Similarly, Smeriglio et al. (2016) characterized phenolic compounds and antioxidant properties of blanched skin and blanch water and compared with unblanched almond skin. During the study, it was observed that blanching causes 60% loss of phenolics in blanching water, and the total phenolic content of blanched and unblanched skin was 313.8 mgGAE/100 g and 703 mgGAE/100 g, respectively. When extract was resolved using RP-HPLC-DAD, 21 flavanons, flavanols, flavonols and phenolic acids were identified, with naringenin being the most abundant compound, followed by kaempferol-3-*O*-rutinoside, kaempferol-3-*O*-glucoside, kaempferol, and eriodictyol-7-*O*-glucoside.

### 21.3.5 Kernel

Abe et al. (2010) reported a total phenolic content of 114 mg/100 g with 1.2 μmol Trolox eq/g) antioxidant activity in toasted almond kernel. Almond kernel extract scavenged 87.30% of DPPH radical, 66.77% hydroxyl radical and 89.50% of ABTS radical with 72.05% metal chelating activity (Serhat et al. 2014). They also reported the presence of kaempferol, naringenin, vanillic acid, caffeic acid, ferulic acid, δ-tocopherol and α-tocopherol in almond kernel. Kiat et al. (2014) extracted antioxidant compounds with 50% aqueous methanol and 100% methanol. They observed higher total phenolic compounds in 50% aqueous methanol (0.33 mgGAE/g) than 100% methanol (0.27 mg/GAE/g) due to the presence of hydroxyl group on the phenol ring, which contributes to its polarity whilst they reported higher radical scavenging activity of 100% methanol extract (68.96%) than 50% aqueous methanol extract (47.69%), which indicated the presence of other than phenolic compounds in extract that are responsible for increased antioxidant properties. Kornsteiner et al. (2006) reported the presence of α-tocopherol (25.9 mg/100 g) and γ-tocopherol (0.9 mg/100 g) in almond kernel. Jambazian et al. (2005) noticed increased levels of α-tocopherol in blood plasma by 12–15% when almond intake in diet increased from 10% to 20%. Polyphenols present in almond are reported to have more bioaccessibility, bioavailability and can metabolize easily by gut microflora and phase 2 conjugating enzymes in comparison to other tree nut Urpi et al. (2009). Almond kernel was found to have appreciable amount of flavonoids (Total flavonoid content 15 mg/100 g) like flavan-3-ols, flavonols, anthocyanins, flavanones and isoflavones (Bradley et al. 2010). Ghazzawi and Ismail (2017) reported decreased flavonoid content and increased phenolic content and radical scavenging activity after roasting than that of raw almond kernel. This can be assumed because of the release of bound phenolic during roasting that are majorly responsible of high antioxidant activity.

## 21.4 Antioxidant Properties of Products Prepared From It

### 21.4.1 Almond Milk

Almond milk is one of the alternatives for lactose-intolerant patients. Almond milk is a colloidal dispersion obtained after mixing water with powdered or pasted almonds. The general method of preparation involves soaking and grinding the almonds with excess amount of water. The milky white liquid is obtained after the solids are filtered (solid content depends on the nut and water ratio). In commercial processing, the milky white liquid is generally homogenized using high pressure and then pasteurized to increase the stability and shelf life. Homogenization and heat treatment of almond milk can improve the physical properties of the product in terms of particle size and viscosity. Wansutha et al. (2018) reported an increase of 47.25% in DPPH scavenging activity of almond milk fermented at 37 °C for 24 h when compared with its unfermented counterpart. Similar trends were recorded for

ABTS and FRAP method. This was confirmed by the presence of more amounts of phenolics in fermented almond milk (270.59 μgGAE/g) than unfermented milk (222.86 μgGAE/g).

### 21.4.2 Almond Oil

Almond contains 50% oil, which is mainly extracted from the sweet almond variety. Oil is extracted by cold press or solvent extraction method. Almond oil majorly contains oleic acid as fatty acid, α-tocopherol as major tocopherol and β-sitosterol as major sterol. Fernandes et al. (2017) reported 60.22% oleic acid, 29.58% Linoleic acid as a major compound, whilst it also contains campesterol, campestanol, stigmasterol, Δ7-campesterol, β-sitosterol, sitostanol, Δ5-avenasterol, Δ5,24-stigmastadienol, Δ7-stigmasterol, Δ7-avenasterol, squalene, phytol, geranylgeraniol, α-tocopherol, β-tocopherol, γ-tocopherol and δ-tocopherol; these compounds possess antioxidant activity. Moreno et al. (2016) extracted almond oil by hydraulic press and screw expeller and estimated total phenols, oxidative stability and sterols, which own antioxidant properties. The total phenol content of hydraulic and screw press extracted oil is 18.8 mg caffeic acid/kg and 22.8 mg caffeic acid/kg, respectively, with oxidative stability of 20.5 (h) and 19.7 (h), respectively. Sterols identified in both the oils are cholesterol, brassicasterol, campesterol, stigmasterol, Δ7-stigmasterol, β-sitosterol, erythrodiol and uvaol. β-sitosterol was among the highest sterol present in almond oil.

## 21.5 Characterization of the Chemical Compound(S) Responsible for Antioxidant Proprieties and the Pathways Involved in the Biological Activities

Almonds are nutritionally enriched food containing proteins, fibre, minerals, vitamins and unsaturated fatty acids (Kamil and Chen 2012). Variety of bioactive compounds including polyphenols such as flavonoids, phenolic acids and tannins are present in almonds imparting high antioxidant properties. Antioxidants in any food product are known to act as protective agents against oxidative attack induced by singlet oxygen molecules, decrease the free radical concentration in the body by scavenging them to inhibit chain initiation reactions, chelate metal ions, terminate the oxidation reactions and generate non radical compounds by decomposing oxidation primary products (Shahidi 1997). Powerful antioxidant capacities of almonds and their skin are mainly due to the presence of flavonoids, triterpenoids and phenolic acids. Since polyphenols are responsible for biological activities of almonds, it is of extreme importance to accurately characterize them in terms of their profiling and respective concentrations.

According to the literature available, polyphenols can be extracted from whole almonds, almond skin, almond shells and blanch almond water. The most common polyphenolic compounds in almond and its skin belong to classes of hydrolysable tannin, phenolic acid, proanthocyanidin and flavonoid including protocatechuic acid, chlorogenic acid, dihydroquercetin, quercetin-3-*O*-glucoside, naringenin-7-*O*-glucoside, isorhamnetin-3-*O*-rutinoside, isorhamnetin-3-*O*-glucoside, eriodictyol, kaempferol, dimer A (gallocatechin-fAf-(epi)catechin), vanillic acid, protocatechuic acid p-hydroxybenzoic acid protocatechuic aldehyde trans-p-coumaric acid and isorhamnetin along with certain other flavonoids (Monagas et al. 2007).

Frequently identified flavonoids in almond and its skin are catechin, epicatechin, epicatechin gallate, gallocatechin gallate, dihydroquercetin, dihydrokaempferol, epicatechin glycoside and dihydrokaempferol. However, the most abundant class of flavonoids present in almond is flavonols including kaempferol, isorhamnetin and quercetin and their derivatives such as galactosides, rutinosides and 3-*O*-glucosides. Morin has been found in almond while isorhamnetin-3-*O*-galactoside was found to be present in its skin. The major flavanones identified in almond and their skins are naringenin, eriodictyol, their glucosides and methoxy flavones. Eridicytol-7-*O*-glucoside is the compound not found in whole almonds, but in skin and blanch water (Bolling 2017). Almond skin has been reported to be a good carrier of water-soluble flavonoids, most of which are lost during blanching process in the industry; therefore, the skin is considered as a by-product with lower commercial value (Saura-Calixto et al. 2007). Glucose, rhamnose, rutinosides and mono-glycosides are the major conjugated sugars present characterizing flavonoids (Mandalari et al. 2010).

Tannins are water-soluble polyphenols, heterogeneous in nature with high molecular weights commonly found in plants having as high as 20 hydroxyl groups (de Jesus et al. 2012). Hydrolysable tannins, subcategory of tannins, are another important class contributing bioactivity to almonds. They are further classified as gallotannins and ellagitannins on the basis of their hydrolysis products. When hydrolysed by weak acids, gallotannins generate sugars along with gallic acid while ellagitannins result in the formation of not only these two compounds but also ellagic acid (Lamy et al. 2016). Xie et al. (2012) reported identification of large molecular weight compounds, 5–6 gallotannins and 6 ellagitannins in almond extracts; however, their comprehensive characterization of parent structure has not been reported even when they are found in sufficient concentrations in almond. Some of the ellagitannins present in walnuts are glansrins, pedunculagin, and casuarictin, suggesting that these may also be found in almonds. Although hydrolysed extracts of defatted almonds demonstrated the presence of gallic acid and ellagic acid, their concentration was 3–10 times lower than that of walnuts.

Another class of tannins, proanthocyanidins, also known as condensed tannins, are polymeric molecules of flavan-3-ols attached by either intermonomer C–C bonds, or an additional ether bond is also present characterized by their unique features and structures. They are categorized as procyanidins when (epi)catechin is present in their structural unit, prodelphinidins with (epi)gallocatechin moieties and propelargonidins due to the occurrence of (epi)afzelechin moieties. There may be the association of the galloyl groups with few of the moieties in the chain (Pérez-Jiménez and Torres 2012). Proanthocyanidins identified in the blanch almond water were (−)-epicatechin (+)-catechin, B-type procyanidin dimer, A-type procyanidin dimer B-type propelargonidin dimer, B-type propelargonidin trimer, B-type procyanidin trimer, B-type procyanidin trimer and B-type procyanidin tetramer (Pérez-Jiménez and Torres 2012). A and B types of interflavan bonds in proanthocyanidins have been reported, majority being B type having bonding between either C4–C6 or C4–C8. However, type A bonding may be between C2–C7 and C4–C6/C4–C8 or C2 → C5 and C4 → C6. The proportion of type B and type A bond along with critical configuration of type A bonds in almonds is yet to be explored (Bolling 2017).

Stilbenes are another class of bioactive compounds present in almonds which are synthesized via phenylalanine, polymalonate and shikimate pathways; however, their concentration is lower in comparison to other polyphenols such as flavonoids and tannins (Jeandet et al. 2010). Xie and Bolling (2014) reported the presence of polydatin in the extract of whole almond, piceatannol and oxyresveratrol in almond blanch water and polydatin in the skin of almonds in the concentrations ranging between 0.1 and 8.5 μg/100 g of almonds; 96–98% of the polydatin was present in the skin of almond which can be efficiently extracted by hot water. These compounds have synergistic bioactivities with other bioactive compounds present in almonds. Quercetin was synergistic to induce caspase-3 activity in laboratory-cultured leukaemia cells and similar synergistic potential of resveratrol was found with ellagic acid, c-tocotrienol and epigallocatechin gallate to induce quinone reductase activity in MCF-7 breast cancer cells (Mertens-Talcott and Percival 2005; Hsieh and Wu 2008).

Lignin's are di-phenolic bioactive compounds holding antioxidant activity, found in the higher plants which are synthesized as a result of coupling of a pair of coniferyl alcohol moieties in the cell wall of plant material (Westcott and Muir 1998). In case of almonds, lignins are present in minor concentration comprising lariciresinol, secoisolariciresinol, pinoresinol, hydroxymatairesinol, syringaresinol, sesamin, cyclolariciresinol, matairesinol and hydroxysecoisolariciresinol as identified by gas chromatography-mass spectrophotometry (GC-MS) in hydrolytic extracts (Bolling 2017).

### 21.5.1 Pathways of Biological Activity of Polyphenols

Polyphenolic compounds are strong antioxidants preventing human body from oxidative stress and related disorders. Free radicals in their native form or as reactive oxygen species (ROS) and reactive nitrogen species (RNS) are responsible for the onset of certain oxidative damages as a consequence of which damage to human body is initiated in various forms. These radicals when react with cellular components alter the structure and functionality membranes, proteins, RNA, DNA, lipids and carbohydrates (Halliwell 1996; Gutteridge and Halliwell 2000). Such condition is referred to as oxidative stress. In other words, oxidative stress is a condition that occurs as a result of damage to body due to non-enzymatic reaction of free radicals, ROS and RNS with cellular and extracellular components threatening their normal functioning (Blomhoff 2005; Blomhoff et al. 2006).

Antioxidant activity of polyphenols depends upon the molecular structure of respective bioactive compounds characterized by geometrical, electronic and conformational features. For a compound to be an effective radical scavenger, it is important that aromatic ring must have multiple OH groups attached with their rearrangement in ortho-dihydroxy conformation. Additionally, the presence of carbonyl bonds and C=C further improves their antioxidant activity (Leopoldini et al. 2011).

Free radical chain reaction is the most common pathway of biological oxidation of lipids. Inhibiting the propagation of these chains is one of the most effective strategies for antioxidant activity. Polyphenols have great affinity to break these chains and act as free radical scavengers due to the presence of OH groups that act through donation of one electron. Radical scavenging activity is also attributed to aromatic rings that stabilize the resonance of aroxyl radicals (Bors et al. 1990).

The biological activity of polyphenols is also a consequence of their interaction with protein molecules in the body. The non-specific mechanism of polyphenols is attributed to common structural features such as OH group, while specific mechanism of antioxidant activity or other biological function is based on the chemical structure of respective compound. For instance, interaction of polyphenols with proteins is specific action and the resultant biological activity is dependent on the native function of that protein such as enhancement in the enzymatic activity, membrane functionality, receptors-ligand binding and transcription activities in relation to DNA (Fraga et al. 2010).

Hydroxy radicals are the most reactive moieties which abstract one hydrogen atom from any target. Hydroxy radicals are generated by several pathways such as reduction of peroxides induced by metals, peroxynitrous decomposition and cellular respiration which generates hydrogen peroxide. These oxidants result in severe damage and stress to cells. Metal ions such as iron are involved in the pathways for the generation of hydrogen peroxide and hydroxy radicals, thereby causing oxidative stress. Polyphenols have the ability to chelate iron, preventing the formation of harmful products of oxidative damage (Perron and Brumaghim 2009). Many of the flavonoids have shown antioxidant and pro-oxidant activities during lipid peroxidation induced by iron with hepatocytes. Such antioxidant potential has been attributed to iron chelation by polyphenols such as catechins and quercetin (Sugihara et al. 1999). Metal-binding impact of polyphenols imparts cytoprotective effects and their antioxidant activity is due to both lipophilicity and iron binding (Perron and Brumaghim 2009).

Interaction of polyphenols with receptors which initiate cell signalling imparts another important biological function. Epigallocatechin 3-gallate, a polyphenolic compound, has been found to directly bind to proteins and lipids of cell membrane inducing inhibition of platelet-derived growth factor-stimulated restenosis. Polyphenols also regulate cellular growth receptors such as tyrosine kinases, insulin receptor vascular, and endothelial growth factor receptor (Kim et al. 2014). Cell metabolism regulation by the action of polyphenols begins after coming in contact with cell surface and penetrating into the cytoplasm through plasma membrane, thereby influencing membrane lipids in terms of osmotic stability, diffusion, intrinsic bilayer curvature and permeability to water-soluble molecules. Their penetration depends upon hydroxyl groups and hydrophobicity of compounds. After the polyphenols attach to the cell surface, lateral segregation of proteins and lipids occurs, resulting in the formation of clusters and then binding the corresponding cells. Such a process is important for cell-to-cell signalling and communication (Tarahovsky 2008).

Digestion and absorption of lipids in the gastrointestinal tract are done with action of enzymes hydrolysing triglycerides, and inhibiting or limiting the activity of pancreatic lipase may result in prevention of hyperlipidemia due to lower absorption of lipids. Sbarra et al. (2005) reported polyphenols influencing the pancreatic lipase activity. For the lipase activity, triglycerides are first emulsified to droplets of fat and the size of these fat droplets defines the surface area for the enzymatic activity (Armand 2007). Polyphenols such as flavanols affect the emulsion properties by increasing the size of fat droplets, thus lowering the availability of potential sites for enzymatic activity due to lower surface area (Fraga et al. 2010).

Although there is an elaborative defence system in the skin against oxidative damage induced by ultraviolet (UV) radiations from the sun, excess of sun exposure may limit natural defensive antioxidant potential and result in oxidative stress, giving birth to many skin-related disorders such as premature ageing, immunosuppression and skin cancers. Since most of the polyphenols are coloured compounds, they have the ability to absorb UV radiations. Application of these polyphenols on skin prevents direct contact of skin and radiations and thus acts as sunscreen, thereby reducing the risk of radiation-induced DNA damage, inflammation and oxidative damage (Nichols and Katiyar 2010).

Polyphenols have been reported for anti-inflammatory activities and one of the important *pathways is the arachidonic acid-induced cyclooxygenase inhibition. The major targets of polyphenols under these arachidonic acid-dependent pathways are nitrous oxide synthase, NSAID-activated gene-1and nuclear factor kB. Enzymatic and transcriptional inhibition of cyclooxygenase modulates gene expression and shows anti-inflammatory effects. It is based on the reduction of synthesis prostaglandin in the arachidonic pathway (Biesalski 2007).

Polyphenols are perceived as xenobiotics and they have very low absorption due to complex structure and polymerization. Remaining 90–95% of them escape digestion and reach in the large intestine where they are exposed to enzymatic action of gut microbiota. Small fraction of polyphenols is absorbed after de-glycosylation in small intestine. Less complex compounds pass through biotransformation reactions in enterocytes and hepatocytes via phase I and phase II comprising hydrolysis, reduction, oxidation and conjugation reactions producing water-soluble metabolites circulated to different organs and then excreted. Unabsorbed polyphenols in the large intestine generate several metabolites by the action of gut bacterial enzymes. Gut microflora generates several bioactive compounds which positively influence host health. Polyphenols in the gut flourish the desirable bacterial strains while inhibiting the growth of pathogens. However, their mode of action depends upon the composition of the cell wall layers (Kumar Singh et al. 2019).

## 21.6 Health Benefits

Almond is a tree nut which is one of the nutri-dense nuts in association with other nuts. Almond is a good source of protein (21.15 g/100 g), fat (49.93 g/100 g), carbohydrates (21.55 g/100 g), dietary fibre (12.5 g/100 g), vitamins (vitamin A- 2 IU, vitamin E- 25.63 mg/100 g, thiamine- 0.205 mg/100 g, riboflavin- 1.138 mg/ 100 g, niacin- 3.618 mg/100 g, folate- 44 μg/100 g) and minerals (calcium- 269 mg/ 100 g, iron- 3.71 mg/100 g), magnesium- 270 mg/100 g, phosphorus- 481 mg/100 g, potassium- 733 mg/100 g) (USDA 2018). Besides, it does contain anti-disease or bioactive compounds, which possess health beneficial effect on consumption. Almond is effective in reducing the risk of coronary heart diseases, cancer and hypertension; lowers LDL-cholesterol; has anti-tumour activity, anti-diabetic activity, hepatoprotective activity; is immune-stimulant; improves wound healing and helps in memory-improving activity and weight loss. Figure 21.4 represents the health benefits of almonds.

### 21.6.1 Almond in Cholesterol Reduction

Earlier, almond was included in the diet of heart patients due to their higher fat content nut. Later, based on clinical studies conducted on healthy individuals as well

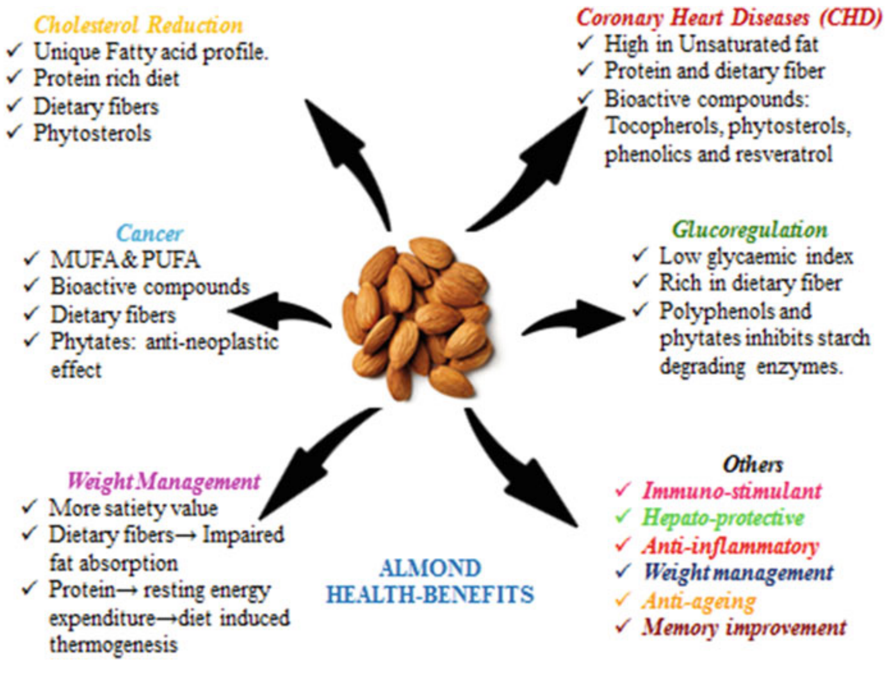


**Fig. 21.4** Health benefits of almonds

as hyperlipidaemia patients, it was concluded that almond lowers LDL cholesterol level with further enhancing the lipoprotein profile. Hyson et al. (2002) in a randomized crossover control trail replaced half of the habitual fat either with whole almond or with almond oil for 6 weeks in 22 normolipemic men and women, and found 54% increase in MUFA with decrease in saturated fat and LDL cholesterol level, and no significant change was observed in the PUFA content. A theoretical approach was used by Ortiz et al. in 2012 to study whether consumption of almond is more effective than reducing dietary saturated fat in decreasing the plasma cholesterol and LDL levels. They observed negative correlation between almond intake and percentage change in cholesterol and LDL levels, whilst no significant changes were observed in cholesterol and LDL reduction after reducing the dietary saturated fat. The model in this study suggests that almond intake was still beneficial in the reduction of cholesterol and LDL level compared to reduction of dietary saturated fat. High unsaturated to saturated fatty acids ratio in almonds is the architect in facilitating a favourable shift in the fatty acid profile of an individual consuming almonds. Berryman et al. (2015) in a randomized controlled feeding study, included 1.5 oz. of almonds/day till 6 weeks of 2 period, in a diet of 48 individual and compared them with individual having identical diet with isocaloric muffin. They concluded that almond reduced non-HDL cholesterol, LDL-cholesterol and central adiposity. Apart from having excellent fatty acid profile, almond contains 21.15% protein, which is 15% of the total energy. Studies reported that diet replacing carbohydrate with protein showed positive effect on LDL cholesterol level (Wolfe and Giovannetti 1991; Appel et al. 2005). Moreover, the presence of dietary fibre and phytosterols also favours decrease in cholesterol levels. Almond contains 192.4 of phytosterols/100 g that interferes with the intestinal cholesterol absorption, and thus lowers the blood plasma cholesterol levels (Kamil and Chen 2012).

### 21.6.2 Almond in Reducing the Risk of Coronary Heart Disease (CHD)

Coronary heart diseases (CHD) develop when artery becomes narrower because of cholesterol build-up in the arteries. Oxidation and levels of plasma lipids are the major cause of CHD. Epidemiologic and clinical studies revealed correlation between nut consumption and cardio-protective activity (Richardson et al. 2009). This can be correlated with the presence of unique fatty acid profile and bioactive compound present in almonds. In randomized crossover study by Jenkins et al. (2002), a dose effect of almond as snack is compared with whole-wheat muffin of same calorific value (22.2% energy) in 27 hyperlipidaemia men and women patients for 1 month. The diets are divided into 3, full almond dose, half almond and half muffin dose and full muffin dose. Diet containing full almonds showed great reduction in lipid plasma level and LDL: HDL cholesterol ratio. They conclude their study by suggesting that almond can be intervened as snack in the diet of hyperlipidaemia patients because it reduces the risk of CHD, which might be due to the protein, fibre and monounsaturated fatty acid in almonds. Penny et al. (2008) studied the effect of different nuts consumption including almond on the CHD. They reported unexpected reduction in the LDL cholesterol level due to the presence of plant protein, micronutrient including calcium, potassium, magnesium and tocopherols and bioactive like phenolic compounds, resveratrol, and phytosterols. In addition, they categorized almond as a cardio-protective agent. Beman et al. (2010) supplemented 60 g almond/day to 30 men with mild hyperlipidaemia (age: 45 years, BMI: 24.29 Kg/m$^2$). They recorded significant reduction in total cholesterol, apolipoprotein, and LDL cholesterol content. Besides, decreasing lipid content, it may also decrease the lipid susceptibility to oxidative modification due to the presence of antioxidants in almond.

### 21.6.3 Almond in Reducing the Risk of Cancer

Nuts are strongly associated with reducing the risk of cancer by many researchers due to the presence of bioactive compounds in the nuts, which decrease oxidative DNA damage. Soriano et al. (2015) studied the effect of nuts consumption (peanut, walnut and almond) on the breast cancer on 97 patients presenting breast cancer and 104 control subjects and Mantel-Haenszel analysis was used. High consumption of nuts was effective in reducing the risk of breast cancer by 2–3 times. The protective effect of anti-disease component present in these nuts, like phytic acid, phytosterol and resveratrol, showed antineoplastic effect in cells of colon, liver, prostate and breast in earlier studies. Lee et al. (2017) revealed inverse relationship between the intake of nuts and risk of lung cancer, regardless of smoking status. This might be explained with the presence of antioxidant compounds like phenolics, tocopherols, sterols and many more in nuts that hamper oxidate DNA damage and lipid peroxidation. Using binary logistic model, Lee et al. (2018) conducted the study on 923 colorectal cancer patients and 1846 control, and nut consumption was categorized as none, $<1$ serving/week, 1–3 serving/week and $\geq$ 3 serving/week. The study revealed that subjects supplemented with $\geq$3 almonds/week were less prone to colorectal cancer for women and men both.

### 21.6.4 Almond in Regulating Blood Glucose

Glucose in blood is regulated by anabolic and catabolic hormones for maintaining homeostatic. Impaired glucose level in blood is manifested by insulin resistance and hyperglycaemia (Kamil and Chen 2012). Li et al. (2010) conducted a 12-week randomized crossover clinical study on 11 female and 9 male 58-year-old type 2 diabetes patients (BMI 26 kg/m$^2$). Results concluded that incorporation of 60 g almond/day in a diet has beneficial effect on glycaemic control, lipid profile, adiposity and can potentially decrease the risk of cardiovascular disease in type 2 diabetes patients. Shah et al. (2011) performed animal study on mice, included 250 and 500 mg/kg ethanolic extract of leaves, flowers and seed of almond in mice diet for 21 days. After 15 days, the blood glucose levels were reduced to 80.6 and 77.6 mg/dl for 250 and 500 mg/kg extracts. Gulati et al. (2017) did inclusion of almond along with the diet in patients with type-2-diabetes for 24 weeks with exercise run period of 3 weeks, and positive effects of almonds were recorded for glycaemic control, lowering LDL, preventing atherosclerosis and inflammations. They suggested that almond can be incorporated along with well-balanced diet, which results in improving hyperglycaemia and cardiovascular diseases. Similarly, Hou et al. (2018), using parallel design, intervened peanut and almond with low-carbohydrate diet in patients with type 2 diabetes. Results showed significant decrease in the fasting blood glucose level and postprandial 2-h blood glucose level in the type-2-diabetes patients. This can either be due to the low initial carbohydrate intake and almonds that again were low in carbohydrate whilst rich in protein and fat. More amount of fat might reduce the gastric emptying rate, which consequently might decrease the carbohydrate absorption. The exact role of almond in decreasing blood glucose level is still at its infancy stage and not clear; therefore, more detailed studies are required to reveal the exact mechanism behind it.

### 21.6.5 Almond in Reducing Weight Management

Energy balance equation reveals that when energy consumption is greater than energy loss per day, these are the situations when the person become overweight or obese. Wien et al. (2003) conducted a randomized study for 24 weeks on 65 overweight subjects (age: 27–29 years; BMI- 27–55 kg/m$^2$), and low-carbohydrate diet was intervened with 84 g almonds/day or self-selected complex carbohydrate diet. Diet supplemented with almond showed greater reduction in weight (−18%), waist circumference (−14%), fat mass (−30%) and systolic blood pressure (−11%). They suggested that almond enriched with low-carbohydrate diet prevents abnormalities associated with metabolic syndrome and causes effective weight loss. This is attributed to the presence of fibre that interferes with the absorption of fat. Abazarfard et al. (2014) conducted a randomized controlled trial for 3 months on 108 overweight women, and the subjects were divided into two groups in which one group was supplemented with almond with hypocaloric diet and other without almond. Weight, waist circumference, waist-to-hip circumference, BMI, blood sugar, diastolic blood pressure, total cholesterol and triglycerides were significantly decreased in the almond-supplemented group. This could be due to the high satiety value of almonds due to high fibre, protein, unsaturated fat and low glycaemic index. Moreover, unsaturated fatty acid may lead to increased resting energy expenditure leading to diet-induced thermogenesis and dietary fibre that delay gastric emptying and subsequent absorption (Jackson and Frank 2014).

### 21.6.6 Other Health Benefits of Almond

Almond consumption may also act as immuno-stimulant, as due to the high-fibre content, it acts as prebiotic which, on ingestion, escapes digestion in the stomach and reaches in gut where it gets fermented by colon bacteria and forms butyric acid, which stimulates the immune system (Mandalari et al. 2008). As these nuts are rich in MUFA and PUFA, they are having the ability to reduce LDL level in blood, which results in protecting the liver. In addition, consumption of almond oil remarkably increased the hepatic superoxide dismutase, glutathione peroxidase and catalase and thereby decreased the malondialdehide level (Jia et al. 2011). Inflammation plays a big role in the progression of cardiovascular diseases (CVD) and type-2-diabetes, and C-reactive protein and interlukin-6 are associated with these diseases. Several studies reviewed by Kamil and Chem in (2012) revealed that almond intake is inversely proportional to the C-reactive protein and interleukins, and thereby reduces the chances of CVD and type-2-diabetes. Almond is rich in magnesium, which is responsible in lowering the blood pressure, and thus, almond act as an anti-hypertensive agent. It is evident from various studies that almond is a rich source of phenolic compounds, tocopherol, phytosterols and resveratrol that act as potential antioxidants, which ultimately reveal almond as an anti-ageing agent.

## 21.7 Conclusion

Though it appears that many research studies are conducted in characterizing the antioxidant compounds in almonds and its by-products, there is dearth of information on the utilization of by-products, especially almond skin and blanch water that comprises ~95% of the total phenolic of almond as preservative or as dietary supplement or as a functional ingredient in the development of convenience product. These by-products are still underutilized and sourced as livestock feed or else discarded, creating pollution. More extensive research is required in characterizing the nutritional and anti-nutritional attributes that promote their usability in the development of value-added food products.

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# Water Chestnut (*Trapa natans*)

22

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**Abstract**

Water chestnut (*Trapa natans*), an aquatic herb found floating in smaller water bodies across temperate, tropical, and subtropical regions, is an abundant source of carbohydrates, proteins, vitamins, minerals, lipids, dietary fibers, and many other phytochemical compounds. Generally, the fruit and other parts of the herb were familiar with the presence of bioactive compounds and possessed various health benefits. Especially, antioxidant activity was observed to be highest in fruit hulls, followed by leaves, roots, and fruit pulp. However, the phenolic compounds were found to be in higher amounts in leaves, followed by hulls, roots, and fruit pulp. Among all parts, the fruit pericarp extract was investigated to have excellent antibacterial activity. On the other hand, the seed flour was used for development of nutritionally enriched bakery products with enhanced flavor, sensory attributes, rheological properties, texture, and porosity. Water chestnut flour-based snacks were reported to possess potential health benefits for celiac patients and were categorized as functional foods. These compounds have protective effects against cancer, neurodegenerative diseases, coronary heart disease, and osteoporosis. Besides these, water chestnut has been found to possess analgesic, anti-inflammatory, antidiabetic, antimicrobial, cytotoxic, antiulcer, neuroprotective, and immunomodulatory activity.

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**Keywords**

Water chestnut · Antioxidant activity · Functional foods · Anti-microbial · Anti-inflammatory

## 22.1 Botanical Name

Water chestnut is known to belong to the family of *Trapaceae*, Order *Myrtales*, Subfamily *Rosidae*, Class *Magnoliopsida*, Subclass *Rosidae*, and Division *Magnoliophyta* (Shalabh et al. 2012).

### 22.1.1 Botanical Description

*Trapa natans* emerges and grows into a rosette, annually, in every spring. The seeds are overwintered in shallow water bodies. Plants are connected by their roots in the soil and keep floating due to their spongy, inflated leaf petioles. The plant consists of a branched stem system, which often develops into 10–15 daughter rosettes and can reach up to 6–8 feet. Inconspicuous whitish flowers with short conical spinous beak are present, through which a radicle is protruded and further develops into leaf axils by summer. Sometimes the seeds are insect-pollinated. Each rosette produces about 15–20 woody nuts which contain a single seed that ripens, dislodges from the plant, and sinks to the bottom to the river soil where they overwinter. Seeds tend to sustain in water for an age of 12 years but mostly germinate within 2 years (Kunii 1988; Winne 1935). The optimum conditions for the growth of water chestnut require water rich in nutrients and moderately alkaline with a depth of 0.3–2 m (Pemberton 1999).

After pollination takes place, abortion of one of the two locules and ovule takes place. The peduncle tends to bend down into the water and further a one-seeded fruit develops (Hummel and Kiviat 2004). There are two unequal cotyledons usually present: one cotyledon is large and starchy that develops within the endocarp and the smaller one is scaled that grows outward from the terminal pore of the fruit (Gleason and Cronquist 1991). The matured fruits release from the peduncles by the rotting process mostly between mid-July and September (Hummel and Kiviat 2004). The fruit disintegrates and reveals the persistent, hard endocarp. The nut is tetrahedral shaped, black colored, with hard and woody spines which are generated from the sepals of the flower. The parent plant reaches death due to the effect of frost in autumn and decomposes rapidly (Muenscher 1944).

### 22.1.2 Introduction

Water chestnut belongs to the *Trapaceae* family, with multiple varieties including Japanese water chestnut (*Trapa japonica*), Chinese water chestnut (*Trapa bicornis*), Devil water chestnut (*Trapa natans*), Princess water chestnut (*Trapa incise*). *Trapa natans* is commonly known as Singhara or Simkhata in Hindi, Karimbolam in Malayalam, and globally as water chestnut. It is a free-floating plant that thrives in shallow waters. It is mostly found in the temperate, tropical, and subtropical parts of the world. It is abundantly found in Southern Europe, Africa, and Asia. Due to its easy-growing nature, the plant was naturalized in North America. The production of *Trapa* slowly moved to Asia. *Trapa* is usually confused with "Chinese water chestnut" (*Eleocharis dulcis* Burm. f., Cyperaceae), which is a spike rush consisting of an edible tuber (Kachare et al. 2016).

Water chestnut (*Trapa natans*) is an aquatic herb, which is found floating in relatively smaller water bodies (lakes, rivers, ponds, and other swampy areas). It has two different types of leaves, first one is submerged in water and grows along the length of the stem, while the other one is rhombohedral in structure with toothed edges and floats on the water surface. The stem is embodied inside the water and has several branches (Hummel and Kiviat 2004).

The fruit is an abundant source of carbohydrates, proteins, vitamins, minerals, lipids, and dietary fibers. Many other phytochemical compounds, mainly phenolic acids, alkaloids, flavonoids, and tannins, can be found (Chiang et al. 2009; Huang et al. 2016). Majorly, the vitamins found in water chestnut are thiamine, riboflavin, pantothenic acid, cobalamin, retinol, ascorbic acid, and tocopherols (Huang et al. 2016). The fruit, as well as other parts of the herb, are well recognized for their bioactive compounds, which are found to possess antioxidant, antidiabetic, anticancerous, antimicrobial, antihyperglycemic, antidiarrheal, antipyretic, diuretic, anti-inflammatory, and antihepatotoxic properties (Kharbanda et al. 2014; Kim et al. 2015; Lin et al. 2013; Malviya et al. 2010; Radojevic et al. 2016). Due to its diverse health benefits, the fruit and other plant parts have been extensively used in traditional medicines for ages (Adkar et al. 2014). Table 22.1 demonstrates a comparative proximate composition of various varieties of freshwater chestnuts.

### 22.1.3 History

*Trapa natans*, also known as water chestnut, was first introduced in the year 1875 in a Middlesex County, Massachusetts circa. Firstly, it was found in ponds of Cambridge, Belmont, and Arlington. Currently, we see these species in Rivers Sudbury and Concord. The growth of *Trapa* is associated with the increase in the pH and nutrient content of the river or pond. In the mid-1940s, the growth of *Trapa* increased exponentially and created a huge nuisance (Countryman 1970). The infested sites were mostly used for leisure activities such as swimming, washing, and boating which were severely obstructed due to the over-explosion in the growth of water chestnut. *Trapa natans* were again spotted in Lake Champlain in the shallow bays of Vermont and New York. The species landed in Lake Champlain from the River Hudson. There were attempts to destroy the plants by herbicides and hand-pulling, which was in turn expensive and time consuming. The entire *T. natans* populations could be defoliated by the adult and the larval feeding of the leaf beetle.

**Table 22.1** Comparative proximate composition of various varieties of water chestnuts

| Parameter | Green water chestnut (*Trapa* sp.) (Faruk et al. 2012) | Red water chestnut (*Trapa* sp.) (Faruk et al. 2012) | *Trapa bispinosa* Roxb. (Alfasane et al. 2011) |
|---|---|---|---|
| Moisture (%) | 62.5 ± 1.16 | 62.7 ± 1.19 | 70.35 ± 1.27 |
| Crude proteins (%) | 0.275 ± 0.03 (only water-soluble proteins) | 0.251 ± 0.04 (only water-soluble proteins) | 4.40 ± 0.48 |
| Crude fiber (%) | 2.13 ± 0.03 | 2.27 ± 0.05 | 2.05 ± 0.03 |
| Total lipids (%) | 0.84 ± 0.02 | 0.83 ± 0.02 | 0.65 ± 0.04 |
| Crude ash (%) | 1.04 ± 0.02 | 1.09 ± 0.03 | 2.30 ± 0.06 |

However, reports have also put light of the fact that species also fed on unrelated plants, particularly like water shield (Ding et al. 2006).

## 22.2 Antioxidant Properties

Antioxidants are the compounds that prevent oxidation of various compounds by donating hydrogen atoms, by chelating metallic ligands, or by quenching singlet oxygen radicals (Gani et al. 2015). They help in preventing cell oxidation and neutralizing the free radicals in our body, thus improving overall health. Research conducted on antioxidants, like polyphenols, obtained from various fruits and nuts suggests their significant role in preventing cardiovascular and cancer diseases (Kris-Etherton et al. 2004; Serafini et al. 2002).

In vitro antioxidant activity of a substance can be determined by various chemical assays such as FRAP assay, or by free radical scavenging methods (ABTS, DPPH, peroxide radicals, oxygen radicals, and nitric oxide-based radicals). In Ferric Reducing Antioxidant Power (FRAP) assay, the antioxidant compound reduces ferric ions to ferrous ions and the antioxidant activity of the extract is directly proportional to the amount of ferric ion reduced to ferrous ion. The 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical combines with antioxidants (free proton scavengers) to become diamagnetic and its color changes from purple to yellow, thus the antioxidant activity of a sample can be determined by examining the change in absorbance of DPPH using spectrophotometric method. Also, 2,2′-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid (ABTS) radical gets stabilized by accepting an electron from the antioxidant compound and the free radical scavenging activity of the extract can be determined spectrophotometrically by examining the amount of ABTS radical getting stabilized in presence of the extract (Rajurkar and Hande 2011).

Most of the antioxidants get accumulated in the skin and shell parts (Bravo 1998). The researches done on antioxidant properties of water chestnuts are quite less as compared to other underutilized crops. However, the studies conducted show enormous assurance in the antioxidant activity of water chestnuts. Many recent researchers have reported the antioxidant potential of water chestnuts, containing large amounts of flavonoids, flavones, and total phenolic contents (Adkar et al. 2014).

Phenolic compounds are an important category of bioactive compounds which act as primary antioxidants. Their activity is mostly due to their redox properties in which they usually neutralize or absorb the free radicals or degrade peroxide radicals and oxygen radicals (both singlet and triplet) (Osawa and OSAWA 1994). Due to these actions, they are proven to inhibit the genetic alteration and growth of carcinogenic cells in the human system (Tanaka et al. 1998). On the other hand, flavonoids are the class of compounds that prevents damage to cells against the destructive effects of major reactive oxygen species and peroxynitrite radicals. Studies have proven that death due to coronary heart disorders and the occurrence of heart attacks is inversely proportional to the amount of flavonoid intake (Wahed et al. 2014).

The strong antioxidant properties of water chestnuts are due to the three major phenolic compound structures (Rice-Evans et al. 1997). You et al. (2007) studied the phenolic compounds present in water chestnut using HPLC and found the peaks as (−)-epicatechin gallate, (−)-gallocatechin gallate, and (+)-catechin gallate. These compounds accounted for about 60% of the total phenolic activity. Reports suggest that the antioxidant activity of phenols is due to the redox characteristics. The extracts of water chestnut were also testified for their high inhibitory activity against α-amylase, a glycolytic enzyme which prevents blood glucose elevation and has exclusive insulin-reducing features, making it an ideal food additive in handling type 2 diabetes (Yasuda et al. 2014).

Phenolic compounds are found to reduce the growth of cancerous cells, reduce cardiovascular problems, and degeneration of neural system (Del Rio et al. 2013). Studies have demonstrated that the leaves of water chestnut have a higher amount of phenolic acids than the kernel itself (Malviya et al. 2010). Table 22.2 depicts the quantitative variation of phenolic acids among various parts of ethanolic extracts of *Trapa natans* plant.

Aleksic et al. (2018) studied the detailed phytochemical properties of *Trapa natans*, mainly found in its floating leaf extracts. These compounds were extracted using methyl alcohol, ethyl acetate, and acetone but only methanolic extract was used further owing to its least toxicity. The study was done by ultrahigh-performance liquid chromatography method to quantify the phenolic compounds. Out of the 22 phytochemical compounds found in *T. natans* extracts, 4 were flavonoids, 7 were glycosides, 10 were phenolic acids and their derivatives, and the last one was *para*-hydroxybenzoic acid. These compounds are listed in Table 22.3. These compounds were either found as such or as the glycosides of corresponding phenolic acids. In all, 19 out of these 22 identified compounds were found to be extracted from T. *natans* leaves with gallic acid, ellagic acid, ferulic acid, and quercetin 3-O-

**Table 22.2** Amount of various phenolic acids in ethanolic extracts of *Trapa natans* L. plant

| Phenolic acid (mg/100 g of dry sample) | Root extract | Leaf extract | Pulp extract | Hulls extract |
|---|---|---|---|---|
| 3-O-methylgallic acid | Not detected | Not detected | 54.61 ± 0.010 | Not detected |
| Chlorogenic acid | Not detected | Not detected | Not detected | Not detected |
| Caffeic acid | 47.16 ± 0.010 | 464.78 ± 0.10 | Not detected | 425.22 ± 0.03 |
| Ferulic acid | 131.01 ± 0.020 | 204.75 ± 0.08 | 9.81 ± 0.008 | 178.92 ± 0.03 |

Source: Stoicescu et al. (2012)

**Table 22.3** List of phenolic compounds extracted from methanolic extracts of *T. natans* leaves

| Category | Name of compound |
|---|---|
| Phenolic acids and their derivatives | Gallic acid hexoside isomer 1<br>Gallic acid hexoside isomer 2<br>Gallic acid<br>Protocatechuic acid<br>Para-hydroxybenzoic acid<br>Para-coumaric acid hexoside<br>Caffeic acid<br>Para-coumaric acid<br>Ellagic acid<br>Para-coumaroyl-di-galloyl-O-glucose<br>Ferulic acid |
| Flavonoids | Quercetin<br>Pinobanksin<br>Naringenin<br>Rhamnetin |
| Flavonoid glycosides | Naringenin-7-O-hexoside<br>Kaempferol di-O-hexoside isomer 1<br>Kaempferol di-O-hexoside isomer 2<br>Rutin<br>Astragalin<br>Quercetin 3-O-rhamnoside<br>Quercetin 3-O-galactoside |

galactoside, and hyperoside being the major ones. Ellagic acid and *para*-coumaric acid were found in the pericarp powder extract.

In a study, Stoicescu et al. (2012) evaluated the in vitro polyphenol content, antioxidant activity, and antibacterial properties of ethanolic extracts of several parts of water chestnut (*Trapa natans L.*) plant. For the analysis, freshwater chestnuts were collected from Danube Delta region in Romania and were divided into four parts, namely fruit pulp, fruit pericarp (hulls), aquatic part (roots), and aerial part (leaves). Bioactive compounds were extracted from the samples using 50% (v/v) aqueous ethanol solution.

Determination of the total polyphenols content was done by UV-visible spectrophotometric method using Folin–Ciocalteu reagent. The phenolic content of samples was expressed in terms of gallic acid equivalents (GAE). The phenolic compounds were found to be much more in leaves (4.902 ± 0.761 mg GAE/g of extract), followed by hulls (2.992 ± 0.294 mg GAE/g of extract), roots (2.765 ± 0.077 mg GAE/g of extract), and the least amount in fruit pulp (0.499 ± 0.110 mg GAE/g of extract). Malviya et al. (2010) also reported that the total polyphenols content of *Trapa natans L.* leaf extract is much higher as compared to that of its fruit kernel extract.

The antioxidant activity of ethanolic extracts of different parts of *Trapa natans L.* was determined using chemiluminescent assay where it was found that antioxidant activity was found to be highest in fruit hulls, followed by leaves, roots, and was least in the fruit pulp. The correlation between total phenols and antioxidants was not found to be linear which also proves that antioxidant activity does not solely depend on the amount of polyphenols present in a sample. Antibacterial activity analysis of ethanolic extracts of various parts of *Trapa natans L.* revealed the absence of antibacterial compounds in the aquatic part, aerial part, and fruit pulp when examined against *Staphylococcus aureus*, *Escherichia coli*, *Proteus vulgaris*, and *Pseudomonas aeruginosa*. However, the extract from fruit pericarp was found to possess antibacterial activity against *Staphylococcus aureus* (at a concentration of $\geq$ 0.03 μg/ml), and *Escherichia coli* (at a concentration of $\geq$ 0.09 μg/ml) (Stoicescu et al. 2012).

Aidew and Buragohain (2014) studied the antimycobacterial and antioxidant activities of *Trapa natans L. Var. Bispinosa* fruits to discover its therapeutic values and health benefits. They extracted bioactive compounds from the whole fruit and its peels by cold extraction method using ethanol, methanol, and water as solvents. The methanolic and ethanolic extracts were analyzed further to determine their total phenolic content, total flavonoid content, FRAP activity and minimum inhibitory concentration (MIC) against *M. tuberculosis* H37Rv and *M. smegmatis*. Total flavonoid content and FRAP activity were found to be highest for ethanolic extract from peels, followed by methanolic extract from peels and least in ethanolic extract from whole fruits while MIC against *M. tuberculosis* H37Rv and *M. smegmatis* were found to double in case of whole fruit ethanolic extract as compared to the other two samples.

However, total phenolic content was observed to be highest in ethanolic extract of peels, followed by ethanolic extract of whole fruit, and minimum in ethanolic extract of peels. Similar trends have been observed in other researches as discussed above. A further study using gas chromatography-mass spectroscopy was performed for identification of phytochemicals present in the ethanolic extract and seven different compounds were identified namely ferulic acid, methyl dodecanoate, methyl tetradecanoate, diethyl phthalate, hexadecanoic acid, adipic acid, and phthalic acid.

A phytochemical study was carried out on the fresh leaves of *Trapa bispinosa* Roxb., collected from Lake Savar, Dhaka, Bangladesh (Wahed et al. 2014). A qualitative analysis of methanolic extracts of leaves revealed the presence of alkaloids, glycosides, tannins, and saponins while steroids and flavonoids were found to be absent. Although, Karmakar et al. (2011) have reported the presence of flavonoids in the ethanolic extract of the fruit, Singh et al. (2016). have reported its absence in the methanolic extract of the fruit. Wahed et al. (2014) reported the total phenolic content of 0.45 mg/g GAE, flavonoid content of 0.74 mg/g quercetin equivalent and total antioxidant activity of 0.84 mg/g in the methanolic extract of *Trapa bispinosa* Roxb. leaves which indicated that ethanolic extract of the samples has much more quantities of phytochemical compounds as also reported by other researchers.

Singh et al. (2016) studied the antioxidant activity (DPPH inhibition activity) of *Trapa bispinosa* plant parts at various concentrations. The yield of methanolic and aqueous extracts was found to be 13% and 13.5% respectively. The phytoconstituents present in both the extracts were pyridoxine, thiamine, nicotinic acid, pantothenic acid, D-amylase, and phosphorylase 2β,3α,23-trihydroxyurs-12-en-28-oic acid. DPPH inhibition activity was found to be 87%, 75%, and 53% for aqueous extract of the plant at concentrations of 20 μg/ml, 40 μg/ml, and 80 μg/ml, respectively, while the methanolic extracts showed 88%, 87%, and 81%, respectively, for the same concentrations of plant extract. This clearly states that the DPPH inhibition activity of aqueous and methanolic extracts was similar at lower concentration of plant extract but was significantly higher in methanolic extracts as the concentration of plant extract in the test sample increases.

## 22.3 Health Benefits

*Trapa natans* or water chestnut (singhara) is a good source of nutrition and has diverse pharmacological effects. It is consumed as raw, boiled, roasted, or grounded after drying to produce water chestnut flour (WCNF) Morrone et al. (2015). WCNF contains more phenolic compounds (4.25 gGAE/1000 g), flavonoids (1.92 gQE/1000 g), and minerals (potassium, magnesium, zinc, and copper) than wheat flour (Shafi et al. 2016). Adding water chestnut flour in the daily diet can fulfil the recommended dietary allowance of 700 mg phosphorus, potassium, and zinc (Yellavila et al. 2015).

Chestnut flour incorporated snacks were found to have higher mineral content viz. potassium, sulfur, calcium, chlorine, and iron. They were reported to possess potential health benefits for celiac disease patients and regarded as functional food (Mir et al. 2019). Many studies have been carried out for the development of diverse bakery products substituting water chestnut flour to enrich the health attributes of these products, where the common base ingredients lack bioactive compounds (Demirkesen et al. 2010; Mir et al. 2019; Singh et al. 2011).

Addition of water chestnut flours is not only restricted with enhancing nutritional content of the product but also improves the sensorial attributes, rheological properties, texture, porosity, expansion ratio in fried products, and flavor (Mir et al. 2019). It is also reported that choice of water chestnut flour over other common flours preferable for bakery and extruded products is because of its high sugar, negligible fat, easily digestible, and helpful for dieting. The combined effect of the constituents of water chestnut flour at optimum temperature increases the browning reactions (Sacchetti et al. 2004).

While studying the pasting properties of water chestnut flour, Mir et al. (2019) observed the property of higher viscosity due to greater structural rigidity alters the swelling properties of the end product. The decrease in pasting temperature associated with the decrease in gelatinization temperature is due to its structural attributes. The decreasing trend of protein is due to the intactness of protein in the soft endosperm of water chestnut (Ahmed et al. 2016). The reduction in particle size not only affects the starch, protein, and fiber but also the water-holding capacity and lipophilic tendency of the WCNF. The granules of flour are polyhedral, smooth, and irregular with "raising dust" appearance due to the adherence of protein and fiber to the starch molecules. The above physical attributes contribute to the nutritional, chemical, and rheological characteristics of the flour (Ahmed et al. 2016).

Water chestnut is a good source of alcoholic compounds. The fruit is consumed as a special food in sacred days, a substitute for cereal in the Indian subcontinent during fasting considering its health benefits and natural antioxidant source (Singh et al. 2011). The fruits are juicy, crisp, and scrumptious and have nutritive value of 2% protein and 16% starch. The kernels are used for their diuretic, aphrodisiac, appetizer, astringent, coolant, and antidiarrheal characteristics (Shalabh et al. 2012). Binding properties of the flour makes its potential application in textile sizing and ice cream industries as a substitute to corn starch. The flavored milk was found to more attain enhanced palatability by addition of water chestnut flour while boiling it. The husk contains dietary fibers and polyphenols. Trapain, euginin, and 1,2,3,6-tetra-O-galloyl-beta-D-glucopyranose (TGG) are the polyphenols present in the husk of *Trapa japonica* known for anticancerous activities and reduction of blood glucose and serum insulin levels (Yasuda et al. 2014). Water chestnut extracts are considered a safe antioxidant source. *Trapa natans* sp. has broad therapeutic properties such as analgesic, anti-inflammatory, antidiabetic, antimicrobial, cytotoxic, antiulcer, neuroprotective, and immunomodulatory activity (Shalabh et al. 2012).

The root extract of *Trapa natans* L. var. *bispinosa* found to have significant analgesic activity. The extracts of *Trapa natans* pericarp and seed possess anti-inflammatory activity. Extract of fruit peels showed significant reduction and normalization in the fasting blood glucose levels. Extract of fruit rind showed antimicrobial activity against Gram-negative bacteria. The red variety has higher antibacterial activity against *Bacillus subtilis* while the green one is more potent against *Staphylococcus aureus* and *Shigella sonnei*. *Trapa bispinosa* extract was also reported to have a neuroprotective effect (Agrahari et al. 2010).

The extracts from various parts of *Trapa natans* is used for the treatment of bronchitis, fatigues, inflammation, anemia, urinary discharges, sore throat, bilious secretions, lumbago, hemorrhages, skin diseases, and eye disorders. The free radical scavenging properties of polyphenolic antioxidants are abundantly present in water chestnuts. These compounds have protective effects against cancer, neurodegenerative diseases, coronary heart disease, and osteoporosis. The antioxidant activity of various organic acids such as fumaric, malic, citric, oxalic, ascorbic and quinic acid present in chestnut leaves and fruits are known for their shielding effect against various ailments. The bioactive compounds like glycosides, flavonoids, phytosterols and tannins in the water chestnut extract are reported to have antioxidant and antiproliferative activities against human colon cancer, human ductal breast epithelial tumor and human breast adenocarcinoma and protection against DNA damage (Gani et al. 2015).

## 22.4 Conclusion

Water chestnut contains an average of 65% moisture and 2% of crude fiber. It is proven to be an abundant source of carbohydrates, proteins, vitamins, minerals, dietary fiber, and a variety of phytochemicals. They also show high antioxidant activity which is mostly found in the skin, leaves, and shell parts of the plant. Flavonoids, flavones, and phenolic compounds from the major component of the antioxidants present. Phenols and phenolic compound own redox properties and (−)-epicatechin gallate, (−)-gallocatechin gallate, and (+)-catechin gallate form majority of the phenolic compounds. Ferulic acid is found most abundantly in the roots, pulp, and hull of the plants. On the other hand, caffeic acid is found in leaves and hulls. The concentration of phenolic compounds descended from leaves, followed by hulls, roots, and lastly in fruit pulp. The methanolic extract of the leaves comprises of alkaloids, glycosides, tannins, and saponins. Compared to the methanolic extracts, ethanolic extraction proves higher efficiency in extracting the phytochemicals. The antioxidant activity is useful in neutralizing the free radicals which in turn prevents the proliferation of carcinogenic cells in the human body. The risk of cardiovascular diseases can also be reduced. India is well known as the diabetes capital of the world. Preventing this is the need of the hour. Extract of water chestnut proves to prevent blood glucose elevation and can be further processed as a food additive. But since the relationship between total polyphenols and antioxidant activity was found to be linear, this might intend the other factors also affect the antioxidant activity. The ethanolic extracts of the peel prove to have antimicrobial activity against *M. tuberculosis* H37Rv and *M. smegmatis.* Water chestnut also holds high treasure of minerals such as phosphorous, potassium, sulfur, calcium, iron, and zinc. It has a perfect combination of essential amino acids, sugar, starch, and dietary fiber. New product development focuses on the addition of water chestnut flour in baked foods and snacks which also improves the sensory parameters. High viscosity can provide the desired swelling or expansion due to reduced gelatinization. Since the protein and fiber stay adhered to the starch molecules, the WCNF is found to be granular and this can be used in products that require a crunchy texture. Anti-nutritional factors in water chestnut are usually determined as oxalate, tannin, phytate, and saponin. Soaking and microwave heating prove to reduce the effect of the anti-nutritional factors after which the plant derivatives can be incorporated in the food products. Apart from all this, each part of the water chestnut plant proves to be beneficial. It provides analgesic, anti-inflammatory, antidiabetic, antimicrobial, cytotoxic, antiulcer, neuroprotective, and immunomodulatory activity. Water chestnut on whole has high nutritional properties and can be incorporated in the food industry as snacks, baked food, ice-creams, beverages, etc.

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# Horse Chestnut

# 23

Syed Insha Rafiq, Khalid Muzaffar, and Syed Mansha Rafiq

**Abstract**

The present study was taken into consideration with various medicinal and health benefits attained through numerous phytoconstituents present in horse chestnut seed/nut. These components prevent several diseases and disorders due to the antioxidant, anti-inflammatory, antiviral, immune-modulatory, spasmolytic, anticarcinogenic and neurodepressive properties of these components. It has been widely used for centuries in traditional medicines as a cure for several diseases and ailments. The pharmacological activities and therapeutic applications are achieved via the bioactive constituents such as saponins, flavonoids, tannins, alkaloids, glycosides, triterpenoids, steroids and phenolic substances that cure various diseases. The most important constituents of horse chestnut are aesculin (coumarin derivative) and aescin (saponin). The seeds/nuts of horse chestnut have also been used in food, feed, cosmetic and toiletry products.

**Keywords**

Horse chestnut · phytoconstituents · anticarcinogenic · antioxidant

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## 23.1 Introduction

Indian horse chestnut or himalayan chestnut (*Aesculus indica*) commonly recognized as *Bankhor* in Himachal Pradesh and *handun* in Kashmir, belongs to family Sapindaceae and is found in moderate regions of Asia, America and Europe at altitudes of 900–3600 m (Santapau and Henry 1973). In Asia it is particularly found in India, Pakistan, Afghanistan and Nepal, and in India, it is found in shady and moist areas of Uttar Pradesh, Himachal Pradesh and Jammu and Kashmir (Zhang et al. 2010; Singh 2006). In Kashmir the tree is usually used for afforestation purpose by forest department but has not been included as an agroforestry tree species as no information is available with respect to propagation, utility and cultural practices (Majeed et al. 2009). It is known to possess medicinal and folk uses (Suter et al. 2006). Its leaves and seeds are used as fodder, branches for making charcoal, wood as timber, etc. The seeds are eaten by bears, monkeys and other wild animals in the forests. The seeds are consumed by the hill tribes during scarcity after steeping in water to remove the bitter components. The powdered seeds are mixed with wheat flour and used in different food preparations (Thakur et al. 2015). The horse chestnut wood is used to produce timber, furniture and cellulose (Bellini and Nin 2005). The timber is used for building, packing cases, cooperage, planking, platters, tea-boxes, boat-fittings, water-troughs, cabinet-making and turnery articles; it is also suitable for mathematical instruments, shoe-heels and match-splints (Anonymous 1985). The hardwood, after suitable dyeing and waxing, has been found to be suitable for high quality pencils. Selected portions are useful for high panelling in railway carriages and for sports goods (Conners 2002). The bark is made into a paste for application on painful, dislocated joints. The horse chestnut stem bark extract has been reported to possess fungicidal properties; flower and leaf extracts have shown pesticidal properties in sugarcane and rice (Anwar and Jabbar 1987). The roots have been used to cure leucorrhoea (Anonymous 1985). The leaf extract possesses antioxidant activity and has shown effective activity against different pathogenic bacteria (Chakraborthy 2009; Bibi et al. 2011). The fruits, seeds and roots have been used traditionally against rheumatism, skin disease, colic disorders, leucorrhoea and vein complaint due to the presence of saponins, fatty oils, glycosides and flavonoids (Zhang et al. 2010; Rana and Datt 1997; Shah and Joshi 1971).

### 23.1.1 History

It is native to Southeast Europe and West Asia and was introduced in England around 1550. It has been observed to be evolved in the high latitudes of north and western North America (Manchester 2001). The generic name "*Aesculus*" has been derived from the Latin word "*esca*" that means food (Thiele et al. 2003). The use of *Aesculus* as a cure for overexertion or cough in horses dates back to the Turks and Greeks and may have acquired the name "horse chestnut" based on its equine use (Bombardelli et al. 1996).

### 23.1.2 Botanical Description

Horse chestnut tree is medium to large sized, reaching up to 100 feet in height, with a short, straight, cylindrical bole and spreading crown, with smooth light brown bark. The leaves are dark green palmate with margins and with five to seven lance-shaped leaflets joined at the same point. The tree yields multi-coloured, mostly white to creamy white flower which blooms with a size of 4–6 inches during the months of May and June, which upon fertilization produces huge quantity of seeds in October–November every year (Wani et al. 2014). The seeds or nuts are dark shiny brown in colour embedded in fruit or capsule light brown colour with green patches. The tree sheds leaves from October to early December and the new leaves appear in April, and flowers during May–June when it is extremely attractive. The leaves and shoots are also used as fodder and fruits eaten by cattle.

### 23.1.3 Cultivation

The seeds/nuts of horse chestnut are collected in the autumn and sown in the early spring and are generally used for its cultivation but should be preserved in sand to prevent mould growth and rot during the winter (Khan et al. 1993). The seeds germinate more quickly when steeped in water (Bhagat et al. 1993). These can be grown in all climatic conditions and types of soil, but grow well in sandy loam with little care required during growth (Maithani et al. 1990). However, the seeds should be collected when fully matured to retain the viability longer as the seeds fall under temperate recalcitrant category that remain viable for short period due to high moisture content (Uniyal and Nautiyal 1996; Harrington 1970). The tree is often planted as ornamental tree on the hills.

The horse chestnut shows a great variability in the biochemical composition of the seed; and the conditions to preserve these recalcitrant seeds for germination have to be provided, which will not significantly affect the reduction of moisture content in the seed (Bonner et al. 1994). The major component responsible for germination of the seed is carbohydrates, that is, starch that provide the energy necessary for the growth. In general, the different biochemical substances present affect the germination and production of good quality seedlings. The germination potential of the seeds depends on the biochemical composition (Stein et al. 1974). Starch and water content improve germination, and the fat content serves as energy source. The proteins play an important role in the structure and prevention of excessive drying of the seeds.

### 23.1.4 Seeds/Nuts

Seeds/nuts that constitute the major portion of fruit are enclosed in the shining black hard capsule or shell and each capsule bears single white cotyledons inside, with a diameter of 3.5 cm outside (Parmar and Kaushal 1982). The ripe seeds are eaten in hilly areas of Kashmir by wild animals but in plains they mostly go waste (Wani et al. 2014). These can be used as nutritional supplement due to high nutritional importance with unique composition of carbohydrates, proteins, minerals, fibre and oil content (Majeed et al. 2010a, b). The seeds have been used as food by different tribes of north and north-eastern India during famine times and also grinded to powder to be used as gruel (Singh and Kachroo 1976).

In addition, the seeds also possess therapeutic properties such as anti-inflammatory, antiviral, cardiovascular diseases, curing piles, rheumatism and wound healing (Kaul 1997; Kaur et al. 2011). The seeds have also improved the quantity and quality of milk (Anonymous 1985).

## 23.2 Chemical Composition and Nutritional Importance of Horse Chestnut

The horse chestnut showed a great variability in the biochemical composition of the seed and contains different molecules of polysaccharides, proteins, lipids, minerals and many minor constituents. The nuts/seeds have been reported to contain 73.97% carbohydrates, 10.99% crude protein, 5.34% oil, 2.66% ash and 3.04% water on dry basis (Jelena et al. 2011). However, the seeds which constitute the edible portion of horse chestnut (*Aesculus indica)* fruit contain moisture (50.5%), starch (38.3%), sugars (5.85%), ash (1.93%) and proteins (0.39%) (Singh et al. 2003).

The horse chestnuts have provided necessary food demand during the Great War and have been saved for human consumption thus proved to increase the national food supply. The matured seed is shiny chocolate brown in colour with a specific gravity of 0.82 (Majeed et al. 2009).

Horse chestnut offers outstanding opportunity for natural foods with good therapeutic values with the growing demand of consumers. It has high nutritional significance with unique composition of crude protein (7.18%), oil content (2.02%), fatty acid composition of oil viz. oleic (57.49%), linoleic (16.91%), palmatic (8.77%), linolenic (7.92%), arachidic acid (5.67%), myristic (1.3%) and mineral elements viz. nitrogen (1.15%), potassium (0.79%), phosphorus (0.18%), calcium (0.08%), sulphur (0.07%), iron (159 ppm), copper (41.2 ppm), zinc (25.6 ppm) and manganese (6.95 ppm) (Majeed et al. 2010a, b). The starch content ranged from 29.76% to 40.37% in horse chestnut seeds with 34% reported by Tucovic (1983), 40–60% reported by Lemajic et al. (1985) and 30–40% reported by Stankovic (1995).

## 23.3 Phytoconstituents

Horse chestnut is well known for its medicinal properties due to the antioxidant, anti-inflammatory, immune-modulatory, antiviral, spasmolytic and neurodepressive activities (Chakraborthy et al. 2009; Zhang et al. 2010). The phytocomponents present in horse chestnut are saponins, flavonoids, tannins, alkaloids, glycosides, triterpenoids, steroids and phenolic substances. The most important of the constituents reported are two principle components viz. aesculin (a coumarin derivative) and aescin (a saponin) (Matsuda et al. 1999). The main active compound in horse chestnut is escin, which is a mixture of saponins with anti-inflammatory, vasoprotective and vasoconstrictor effects (Srijayanta et al. 1999).

Aescin also known as escin, is a mixture of triterpene saponins and is known to be the main bioactive component of horse chestnut seeds (Mete et al. 1994). Aescin exists in two forms as α-aescin and β-aescin. β-Aescin is made up of 30 components, which are derived from protoaescigenun and barringtogenol, occurring in the ratio of 8:2 (Wu et al. 2012; Bombardelli et al. 1996). Seed oil contains 65–70% oleic acid. Other constituents include phenolic acids, coumarin derivative aesculin and hydrocarbons such as squalene, nonacosane and cyclitols (Stankovic et al. 1987). The flavonoids present include flavonols and their glycosides and flavanones and their derivatives (Hu and Zeng 2004). The quercetin and kaempferal are types of flavonol glycosides, and proanthocyanidin and polymerized epicatechin are types of flavanone derivatives (He 2000). The saponins have a trisaccharide chain with a glucuronopyranosyl unit attached to the aglycone and are classified as polyhydroxylated triterpenoid glycosides based on four different aglycones (sapogenins) (Walthelm et al. 2001).

## 23.4 Biological Functionality

Horse chestnut has been used for varicose veins, respiratory infections, cardiovascular diseases and severe diarrhoea due to astringent, antipyretic and antithrombic properties. It has been used externally to treat frostbite, ringworm, haemorrhoids, cuts and bruises (Bombardelli et al. 1996). The coumarin component of horse chestnut has been used in sunscreen preparations. The oil of the seeds has been broadly used in pharmaceutical and chemical industries due to antifungal and antibacterial activity (Anonymous 2000). The seeds also possess anti-inflammatory, antitumor, antioxidant, antiviral, anti-cancer, anti-obesity and antigenotoxic properties (Bibi et al. 2012).

The traditionally therapeutic benefits of horse chestnut as herbal remedy for treating chronic venous insufficiency (CVI), postoperative oedema and haemorrhoids are due to anti-inflammatory activities (Kahn 2006; Wichtl 2004; Pittler and Ernst 1998).

The anti-inflammatory activity is due to the aescin compound (Leach and Leach 2001; Matsuda et al. 1997) that releases the inflammatory mediators by decreasing leucocyte activation and adhesiveness and inhibits the activity of hyaluronidase enzyme (Zhang et al. 2010). The activity of the enzyme is inhibited by preventing breakdown of the main compound hyaluronic acid that supports the capillary walls by preserving the matrix. The escin helps to increase the flow of blood and the elastic and contractile properties of veins without increasing blood pressure (Sirtori 2001), and improves capillary strength through anti-excudative vascular tightening effect and reduction of vascular permeability which result in an anti-oedemic effect (Strzelecka and Kowalski 2000).

The antioxidant properties attained by saponins are attributed towards the increased antioxidative defence system of the body that prevented the lipid peroxidation thus inhibiting the adverse effects of oxidative stress and protects the body (Felixsson et al. 2010). The anti-obesity effects are attributed through the restraint of digestion and fat absorption through pancreatic lipase inhibition (Kimura et al. 2008). The extracts of seeds have proved to be effective adjuvant in compression therapy and a substitute for medical treatment and have been used in homeopathic medicine to treat a range of conditions (Sirtori 2001). The saponins have been shown to possess potent hypoglycaemic properties (Leach and Leach 2001). The seeds also possess antimicrobial proteins that inhibit growth of a broad range of fungal species (Fant et al. 1999). The rutin flavonoid of horse chestnut possesses antiviral, antibacterial and radical scavenging properties and the quercitrin and isoquercitrin possess antibacterial activities (Tiffany 2002). The β-escin has been reported to prevent strokes (Hu et al. 2004) and has also shown effective antiviral properties against the growth of cucumber mosaic virus (CMV) (Singh et al. 2004).

## 23.5 Health Benefits

The seeds possess therapeutic importance in human and veterinary medicines such as treatment of fevers, curing piles and constipation. Aescin known for its anti-inflammatory and anti-oedemic properties has been used in tropical ointment applications and oral preparations (Bruneton 1996). Flavonoids also have protective effect on blood vessels, and are well known, powerful antioxidants (Wilkinson and Brown 1999). The seeds contain oil that has been used in rheumatism and applied to wounds (Sharma 1991).

The seeds/nuts also possess antiviral, cardiovascular diseases, curing piles, rheumatism and wound-healing properties (Kaur et al. 2011). Seeds were used to cure colic disorder in horses (Anonymous 1985). The seeds have been used as astringent and nutrient (Badoni 2000), whereas the oil has been used in skin disease treatment (Manandhar 2002; Parmar and Kaushal 1982). The medicinal and health benefits of the seeds are attributed to the presence of phytochemicals such as flavonoids, saponins, glycosides and fatty oils that prevent disease due to the antioxidant effect (Zhang et al. 2010). The extract from seeds has been considered active against leukaemia and human epidermoid carcinoma of nasopharynx (Anonymous 2000). The seed coat contains several triterpenoids that possess health benefits (Sati and Rana 1987).

## 23.6 Utilization in Food and Feed

The seeds have been consumed as food in Chuwar valley of Mandi and have also been consumed as *phalahar* (non-cereal food) during fasts (Rajasekaran and Joginder 2009). The seeds/nuts have also been consumed as food by different races of north-eastern India during famine times (Singh and Kachroo 1976). The seeds/nuts have been used as fodder in eastern countries for feeding cattle and horses with relish and in forests these are eaten by wild animals such as monkeys, bears and others. The seeds as feed in cattle improve the quality and quantity of milk.

The seeds have found applications in toiletry and cosmetics where the juice from seeds has been used in bath oils for a foam bath. The seeds have been used as gruel after ground into powder. The crushed seeds have been used for washing clothes (Rajasekaran and Joginder 2009). Seeds have been used to cure various diseases such as fevers, piles, wound healing, viral infections and cardiovascular diseases (Kaul 1997). The oil from the seed has been used to treat skin disease, rheumatism and relieve headaches. The seeds were used as remedy for horses suffering from colic and as an anthelmintic for intestinal parasites[1]. The bioactive components from bark, bud, flowers and other parts of the plant are used in different herbal specialties for targeted individuals (Deli et al. 2000).

## 23.7 Conclusion

The horse chestnut has revealed adequate evidence for clinically important activity in haemorrhoids, cardiovascular diseases, piles, rheumatism, wound healing, chronic venous insufficiency and postoperative oedema due to its anti-inflammatory, antioxidant, antiviral, anti-obesity and antigenotoxic properties. These properties are attained by the presence of phytoconstituents such as saponins, flavonoids, tannins, alkaloids, glycosides, triterpenoids, steroids and phenolic substances. The saponin constituent "escin" has been widely used in the treatment of peripheral vascular disorders. The seeds possess good composition of nutritional profile and have been used in food, feed, cosmetic and toiletry products as well. Moreover, very less work has been done on the plant so far.

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# Sweet Chestnut

# 24

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**Abstract**

Sweet chestnut (*Castanea sativa*) is one of the most interesting foods in the modern world offering a great diversity in cultural values, production, consumption, functions, economy and environmental aspects particularly of the developed countries. After having originated from the Mediterranean regions, sweet chestnut was brought into Europe by the Romans. The chestnut production has been increasing over the years with China leading the global production. In the present times, sweet chestnut is considered a prized food and vital in sustainable agroforestry. The deciduous tree has a strong and expanded root system working in a symbiotic mycorrhizal association. Flowering of the monoecious tree occurs from the mid of May to June. The green cupule around the flowers forms the chestnut bur that ultimately encases the dark brown nuts. Sweet chestnut mainly comprises of moisture (48.64–54.26%), starch (42.68–73.35%), protein (2.71–7.47%), fibre (2.06–2.79%), fat (0.80–3.80%) and ash (0.77–2.40%). Sweet chestnut and its by-products including bark, leaves, catkin and peel contain nutraceutical compounds (vitamin C, vitamin E, ellagic acid, gallic acid, hydrolysable ellagitannins and gallotannins) having vital health implications. These compounds have antioxidant activities, anti-carcinogenic activities, cardioprotective activities and antimicrobial activities. As such, sweet chestnut and its by-products could be a great prospect for exploitation as medical foods.

**Keywords**

*Castanea sativa* · Sweet chestnut · Tannins · Phenolic compounds · Nutraceuticals

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## 24.1 Introduction

According to The Editors of Encyclopaedia Britannica (2019), *Castanea sativa* is commonly called sweet chestnut, Spanish chestnut or Eurasian chestnut. Sweet chestnut belongs to the *fagaceae* family of flowering plants. Cultivation of the deciduous tree is far and wide across the temperate regions of the world, native to Asia Minor and southern Europe. The use of chestnut seed as a staple food in Europe dates back to the middle ages (Bounous and Marinoni 2005). The study of chestnut throughout its history and in terms of cultural values offers a great diversity in function, economy and environment. Over the years, it has been an interesting subject for the researchers owing to its production and consumption patterns, especially in the developed countries.

### 24.1.1 History

Sweet chestnut has its probable origin around the Mediterranean region millions of years ago (Adua 1999). After surviving the harsh glacial period, chestnut was scattered into the main refugia including Transcaucasia, the Italian and Iberian Peninsulas, Marmara coast and western Syria-Lebanon (Krebs et al. 2019). However, the refugia with medium possibilities include the French Isere Department, north-west Portugal and Galicia and the Mediterranean coast of Syria and Lebanon (Krebs et al. 2004). The introduction of sweet chestnut in Europe is credited to the Romans. However, during that period, the production of chestnut was restricted to just the Insubrian region of the Italian peninsula. Therefore, it is believed that food had not been the probable reason for the Romans to bring chestnut into Europe and the people developed an interest in chestnut fruit production due to socio-economic reasons post-Roman era (Conedera et al. 2004).

### 24.1.2 Production

In the modern times, sweet chestnut is considered as prized rather than a staple food. However, it is still considered vital in sustainable agroforestry. Table 24.1 provides the latest insight into the global production scenario of chestnut (FAOSTAT 2018). The main contributors to chestnut production include Albania, Azerbaijan, Bolivia (Plurinational State), Bosnia and Herzegovina, Bulgaria, Cameroon, Chile, China, Democratic People's Republic of Korea, France, Georgia, Greece, Hungary, Italy, Japan, Kenya, Latvia, Malawi, North Macedonia, Peru, Poland, Portugal, Republic of Korea, Romania, Russian Federation, Slovakia, Slovenia, Spain, Switzerland, Trinidad and Tobago, Ukraine and Zimbabwe. According to the most recent reports, a total of 612,877 ha land is under the chestnut production in the world that produced 1,965,351 tons of chestnut. The chestnut production has increased over the years and more land has been dedicated to its production. Out of all the major chestnut contributing nations of the world, China has the highest area under chestnut

**Table 24.1** Global chestnut production trends

| Year | Area (ha) | HA (Country) | Yield (hg/ha) | HY (Country) | Production (t) | HP (Country) |
|---|---|---|---|---|---|---|
| 2014 | 560,133 | 297,000 (China) | 36,675 | 130,000 (Romania) | 2,054,266 | 1,685,758 (China) |
| 2015 | 558,436 | 289,100 (China) | 36,479 | 116,667 (Romania) | 2,037,146 | 1,660,059 (China) |
| 2016 | 598,776 | 330,433 (China) | 37,871 | 110,000(Romania) | 2,267,617 | 1,889,964 (China) |
| 2017 | 603,919 | 334,020 (China) | 38,048 | 103,333(Romania) | 2,297,790 | 1,918,939 (China) |
| 2018 | 612,877 | 340,597 (China) | 38,406 | 74,000(Romania) | 2,353,825 | 1,965,351 (China) |

Source: (FAOSTAT 2018)
*ha* hectare, *hg/ha* hectogramme per hectare, *t* ton, *HA* highest area, *HY* highest yield, *HP* highest production

production corresponding to the highest annual production. However, Romania produces the highest yield out of its chestnut producing area, which could be because of the better suitability of chestnut production in this country. In India, sweet chestnut is cultivated in the north-eastern Himalayan regions including Himachal Pradesh, Uttarakhand, the Khasia Hills of Meghalaya, Punjab and few regions of Jammu and Kashmir (Saleh 2003; Sharma 2004).

### 24.1.3 Botanical Classification

The systematic classification of sweet chestnut is given below:

| | |
|---|---|
| Kingdom: | Plantae |
| Class: | Magnoliopsida |
| Order: | Fagales |
| Family: | Fagaceae |
| Genus: | *Castanea* |
| Species: | *Sativa* |

### 24.1.4 Botanical Description

Sweet chestnut has a strong and expanded root system that grows deep into the soil. The smallest roots of the tree are in symbiotic mycorrhizal association (Bounous and Marinoni 2005). According to The Editors of Encyclopaedia Britannica (2019), sweet chestnut tree can attain a height of up to 30 m and is deciduous in nature. The leaves are deciduous, about 20 cm long, shiny, lanceolate, having serrated margins with parallel venation and are considered characteristic of sweet chestnut (Saleh 2003). The flowering occurs from the mid of May to June (Bounous and Marinoni 2005; Guo and Feng 2014). Sweet chestnut is monoecious. Both the staminate and pistillate flowers occur in two different types of catkins on the same tree. The unisexual catkins occur at the base while bisexual catkins occur towards the distal end of the shoots (Bounous and Marinoni 2005). Staminate flowers are spirally arranged along the unisexual or bisexual catkins. Stamens with long filaments and fertile anthers are only present in staminate flowers. Pistillate flowers are present in the form of globular inflorescence with three flowers in each inflorescence. The flowers have a green protective covering that develops into the cupule, leading ultimately to the chestnut bur. Around six ovules are present in each flower that give rise to a single-seeded or multi-seeded chestnut. The flowers of sweet chestnut bloom when leaves are completely open and generally depend upon anemophilous cross-pollination as these are self-infertile (Bounous and Marinoni 2005). The sweet chestnuts are dark brown nuts encased in a spiny shell husk or bur.

### 24.1.5 Nutritional Composition

Sweet chestnut is one of the greatly appreciated foods in Europe, America and Asia, owing to its versatile nutritional composition and safety (Romano and Aponte 2019). The proximate composition of sweet chestnut described by various researchers is provided in Table 24.2. The main nutritional components of sweet chestnut on dry weight basis include moisture (48.64–54.26%), starch (42.68–73.35%), protein (2.71–7.47%), fibre (2.06–2.79%), fat (0.80–3.80%) and ash (0.77–2.40%). Sweet chestnuts generally contain high amount of starch and low fat content. The composition of sweet chestnuts varies highly with respect to cultivar and the year of harvesting (Neri et al. 2010).

The moisture content of sweet chestnuts generally varies with the annual amount of rainfall. Sweet chestnuts with high fibre content are not preferred by the consumers because of their low digestibility (Pereira-Lorenzo et al. 2006). Many different mineral elements present in sweet chestnut including potassium, phosphorus, calcium, magnesium, sodium, zinc, copper, iron and manganese are present in Table 24.3. These mineral elements are present in small quantities of dietary significance and the concentration varies widely (Pereira-Lorenzo et al. 2006; Borges et al. 2008).

The fatty acid composition of sweet chestnut is presented in Table 24.4. The fatty acids mainly present in sweet chestnut include C14:0 (Myristic acid), C15:0 (Pentadecylic acid), 16:0 (palmitic acid),16:1ω7 (palmitoleic acid),17:0 (margaric acid), 17:1 (margaroleic acid), 18:0 (stearic acid), 18:1ω9 (oleic acid), 18:2 (linoleic acid), 18:3 (α–linolenic acid), 20:0 (arachidic acid), 20:1 (eicosenoic acid), 22:0 (behenic acid) and 24:0 (lignoceric acid) (Borges et al. 2007; Barreira et al. 2009). The polyunsaturated fatty acids (PUFA) and monounsaturated fatty acids (MUFA) predominate in sweet chestnuts with the saturated fatty acids (SFA) accounting for approx. 17% only. Linoleic acid predominates in sweet chestnut followed by oleic and palmitic acids. Oleic acid is well known for inhibition of inflammation and prevention of cancer (Lamy et al. 2016). Besides, α-linolenic acid is also present in significant concentration. All the other fatty acids are present in very small quantities.

## 24.2 Antioxidant Potential and Health Implications

Sweet chestnut contains very high amounts of vitamin C (400 to 693 mg/kg db), vitamin E and phenolic compounds (ellagic and gallic acids) that are well known for their antioxidant potential in the biological system (Gonçalves et al. 2010; De Vasconcelos et al. 2007). Cooking of sweet chestnut through boiling and roasting results in 25–54% and 2–77% reduction of vitamin C, respectively. However, its antioxidant activity is enhanced after cooking due to a possible leaching of gallic acid from the chestnut peel into the fruit (Gonçalves et al. 2010). Different types of heat treatment including conventional roasting and microwaving improve the antioxidant potential of sweet chestnut (Chang et al. 2016; Wani et al. 2017).

**Table 24.2** Proximate composition (%, dry weight basis) of sweet chestnut

| Moisture | Starch | Protein | Fibre | Fat | Ash | References |
|---|---|---|---|---|---|---|
| 53.44 ± 3.61 | 73.35 ± 7.51 | 7.47 ± 0.85 | 2.60 ± 0.29 | 2.03 ± 0.57 | 2.40 ± 0.32 | De La Montaña Míguelez et al. (2004) |
| 54.26 ± 4.14 | 56.17 ± 5.36 | 5.90 ± 0.94 | 2.68 ± 0.38 | 2.99 ± 0.59 | 2.30 ± 0.27 | Pereira-Lorenzo et al. (2006) |
| 50.66 ± 2.58 | 42.68 ± 3.26 | 5.80 ± 0.84 | – | 2.47 ± 0.43 | 1.88 ± 0.24 | Borges et al. (2008) |
| 52.97 ± 1.24 | – | 2.71 ± 0.39 | 2.06 ± 0.25 | 0.80 ± 0.02 | 0.77 ± 0.09 | Barreira et al. (2009) |
| 48.64 ± 4.02 | – | 4.60 ± 0.37 | 2.79 ± 0.07 | 3.80 ± 0.60 | 1.99 ± 0.44 | Neri et al. (2010) |
| **48.64–54.26** | **42.68–73.35** | **2.71–7.47** | **2.06–2.79** | **0.80–3.80** | **0.77–2.40** | |

Data are presented as mean ± standard deviation of all the samples analysed in each reference

**Table 24.3** Mineral composition (on dry weight basis) of sweet chestnut

| | Pereira-Lorenzo et al. 2006 | Borges et al. 2008 |
|---|---|---|
| Potassium | 0.90 ± 0.08[a] | 754.50 ± 209.71[c] |
| Phosphorus | 0.18 ± 0.06[a] | 123.62 ± 14.43[c] |
| Calcium | 0.04 ± 0.00[a] | 44.75 ± 3.41[c] |
| Magnesium | 0.06 ± 0.01[a] | 74.58 ± 10.18[c] |
| Sodium | 0.008 ± 0.006[a] | 1.72 ± 1.29[c] |
| Zinc | 12.31 ± 1.73[a] | 1.99 ± 0.56[c] |
| Copper | 7.19 ± 1.13[b] | 1.88 ± 0.49[c] |
| Iron | 18.01 ± 2.62[b] | 7.35 ± 1.78[c] |
| Manganese | 41.39 ± 26.09[b] | 5.34 ± 1.55[c] |

Data are presented as mean ± standard deviation of all the samples analysed in each reference
[a] = %, [b] = mg/kg and [c] = mg/100 g

**Table 24.4** Fatty acid profile (%) of sweet chestnut

| | Barreira et al. 2009 | Borges et al. 2007 |
|---|---|---|
| C14:0 | 0.14 ± 0.02 | 0.17 ± 0.06 |
| C15:0 | 0.11 ± 0.02 | 0.14 ± 0.04 |
| C16:0 | 15.20 ± 1.41 | 14.40 ± 1.14 |
| C16:1 | 0.31 ± 0.03 | 0.95 ± 0.18 |
| C17:0 | 0.23 ± 0.08 | 0.14 ± 0.02 |
| C17:1 | 0.15 ± 0.02 | 0.11 ± 0.10 |
| C18:0 | 0.92 ± 0.04 | 0.90 ± 0.12 |
| C18:1 | 33.70 ± 3.50 | 29.4 ± 4.53 |
| C18:2 | 42.00 ± 3.52 | 45.2 ± 3.56 |
| C18:3 | 5.65 ± 1.11 | 6.36 ± 1.84 |
| C20:0 | 0.36 ± 0.04 | 0.27 ± 0.03 |
| C20:1 | 0.78 ± 0.05 | 0.59 ± 0.07 |
| C22:0 | 0.28 ± 0.04 | 0.22 ± 0.06 |
| C24:0 | 0.11 ± 0.02 | 0.15 ± 0.18 |
| SFA | 17.40 ± 1.41 | 16.4 ± 1.24 |
| MUFA | 35.00 ± 3.46 | 31.00 ± 4.52 |
| PUFA | 47.70 ± 4.41 | 51.70 ± 4.91 |

Data are presented as mean ± standard deviation of all the samples analysed in each reference

The inner shell extract of chestnut has total polyphenol and flavonoid content of 532.96 mg gallic acid equivalents/100 g and 12.28 mg quercetin equivalents/100 g, respectively. Against *Campylobacter jejuni* strains, it has a minimum inhibitory concentration of 1–5 mg/mL (Lee et al. 2016). Quorum sensing is a process by which bacteria communicate the release of toxins through signal molecules and assess their population density. The bacteria are able to regulate the gene expression through this process. According to the study of Quave et al. (2015), the oleanene and uresene derivatives of sweet chestnut leaf extract resulted in the accessory gene regulator (agr)-mediated quorum sensing inhibition of *Staphylococcus aureus* and blocked the exotoxins production at subinhibitory concentrations for growth. The gene regulator regulates the process of bacterial pathogenesis involving disruption of epithelial barriers, neutrophil cytolysis and inactivation of antimicrobial peptides. The antimicrobial activity of sweet chestnut's catkin extract has been reported by Mujić et al. (2011) against Gram-positive (*Salmonella typhimurium*) and Gram-negative bacteria (*Micrococcus pyogenes* and *Staphylococcus aureus*). The antimicrobial activity of sweet chestnut is credited mainly to its phenolic compounds including rutin, naringenin, apigenin and kaempferol. However, rutin and apigenin possess the highest antimicrobial activities among others. Exposure of parasitic worms to the extract of sweet chestnut results in complete prevention of exsheathment. Therefore, the larvae are not able to transform into parasites.

The aqueous extracts of different sweet chestnut parts including leaves, catkin and peel possess substantial hydroxyl and 2, 2-diphenyl-1-picryhydrazyl (DPPH) radical scavenging abilities. However, the leaves and peels particularly protect the liposomal peroxidation (Živković et al. 2009). Phenolic extracts of the leaf, catkin and burs of sweet chestnut have been reported to protect the pancreatic β-cell DNA under oxidative stress, thereby preventing diabetes (Mujić et al. 2011). Besides, the leaves are reported to prevent photoageing and other skin diseases arising from oxidation processes (Almeida et al. 2008). Topical application of the phenolic extract of sweet chestnut leaf is regarded as safe with respect to skin irritation in vivo (Almeida et al. 2008).

The chestnut bark contains tannins that are generally classified as ellagitannins (Zywicki et al. 2002; Sanz et al. 2010). However, these may also contain gallotannins as ellagitannins are synthesized in the plant from pentagalloyl glucose, also called gallotannin (Zywicki et al. 2002). Gallotannins and ellagitannins are hydrolyzable tannins (Khanbabaee and Van Ree 2001). In the gallotannins, galloyl esters are linked to the core β-penta-galloyl-D-glucopyranose in different ways. However, in case of ellagitannins, the galloyl esters are specifically linked at 2,3- and/or 4,6- positions of a CL-glucopyranose (Pouységu et al. 2011). Vescalin, castalin, gallic acid, vescalagin, 1-O-galloyl castalagin, castalagin and ellagic acid are the principal tannins and phenolic compounds present in the bark of sweet chestnut (Comandini et al. 2014). Ellagitannins are metabolized into urolithins that are responsible for their high antioxidant potential (Bialonska et al. 2009). Besides antioxidant potential, ellagitannins show effects against atherosclerosis, thrombosis, inflammation and angiogenesis (Larrosa et al. 2010). Sweet chestnut flour contains higher lignans including the isolariciresinol, lariciresinol, secoisolariciresinol and pinoresinol as compared to soft wheat, chick-pea, green and red lentils (Durazzo et al. 2013).

Sweet chestnut bark extract acts as an antispasmodic agent (Chiarini et al. 2013) through modulating cholinergic receptors and calcium channels (Budriesi et al. 2010). To assess the cardioprotective effect of sweet chestnut bark extract, Chiarini et al. (2013) employed the cardiomyocytes of neonatal rats and observed a reduction in the generation of intracellular reactive oxygen species (ROS) and increased viability of cells' postoxidative stress. They also analyzed the cardioprotective effect in vitro using the same extract on guinea pig atria, papillary muscle and aortic strips, which resulted in decreased noradrenalin-induced contraction in the atria.

Chestnut shell polyphenolic extract exerts anti-carcinogenic activity on human hepatocellular carcinoma (HePG2) cell line through the alteration of vascular endothelial growth factor and tumour necrosis factor (TNF)-α (Sorice et al. 2016). A couple of triterpenoids including chestnoside A and chestnoside B were discovered by Pérez et al. (2017) from the heartwood of sweet chestnut and analyzed for their potential against breast (MCF-7) and prostate (PC3) cancer cells. It was found that the triterpenoids were more effective against MCF-7 cells than the PC3 cells. Because of a conjugated double bond, chestnoside B showed more anti-cancerous property than chestnoside A.

## 24.3 Conclusion

Sweet chestnut is one of the greatly appreciated foods in Europe, America and Asia, owing to its versatile nutritional composition, which generally consists of a high amount of starch and a low fat content. Although China is the leading producer of sweet chestnut, yet Romania is most suitable for chestnut production and produces the highest yield out of its chestnut producing area. Besides the nut, the aqueous extracts of different sweet chestnut parts including leaves, catkin and peel possess antioxidant abilities. The ellagitannins show effects against atherosclerosis, thrombosis, inflammation and angiogenesis. The polyphenolic extracts and the triterpenoids exert anti-carcinogenic activity on hepatocellular carcinoma and breast cancer. Having caught interest of the modern world owing to its composition and health-promoting abilities, it could be concluded that sweet chestnut and its by-products have a great scope for further exploration by the food and pharmaceutical industries.

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# Pistachio

# 25

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**Abstract**

Pistachio (*Pistacia vera* L.) belongs to *Anacardiaceae* family (cashew family). Pistachio is the only nut in the 11 species of the genus *Pistacia* containing an edible kernel covered in a hard shell, while all other species produce resins. Pistachio is a native of minor Asia and is largely dispersed in the Mediterranean region that includes the United States and Turkey also. Pistachio nuts are abundantly rich in antioxidants and are being placed recently in the list of 50 foods which are high in antioxidant capacity. Pistachios are also rich source of nutrients such as phenolic compounds, healthy fatty acids and proteins. Pistachios have grabbed the attention of researchers due to the extensive study on the different parts of this plant such as leaves, hulls, kernel, gums and hull which indicate carious beneficial activities such as antimicrobial and anti-inflammatory which are mainly attributed to the presence of flavonoids and phenolic compounds. The present chapter provides information about the antioxidants present in different parts of pistachio nut, its related food products and health beneficial effects on human health.

**Keywords**

Pistachio · Antioxidant potential · Phenolic compounds · Fatty acids

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## 25.1 Introduction

Pistachio is a nut which is a member of the cashew family *Anacardiaceae.* Arid zones of West and Central Asia are native of pistachio nut, and it is distributed widely over the Mediterranean basin. The word pistachio has been adapted from the ancient Persian language which is pista-pistak (Kashaninejad and Tabil 2011) and has similarities with the word ‘Peste’, a modern Persian word. According to Dioskurides, the word pistachio has been adapted from the word pissa which refers to resin aklomai, meaning ‘to heal’, that is collectively known as a plant with healthy resin. The genus *Pistacia* has different species which are collectively called as pistachio. About 20 species of shrub produces pistachio which include *Pistacia terebinthus*, *Pistacia khinjuk*, *Pistacia vera*, *Pistacia atlantica and Pistacia lentiscus* which are the members of cashew family known as *Anacardiaceae*. In different languages, the common name of pistachio is different such as *Peste* in Persian, *Pista* in Indian, *Pistache* in French, *Pistacho* in Spanish and *Fustuq* in Arabic.

### 25.1.1 History

Pistachio has been originated in South Western and Central Asia. Earlier people made use of pistachio trees for the purpose of generating fuel and for cattle grazing. The presence of pistachio nut in archaeological excavations gives the information that pistachios are linked with human activities since ages. The cultivation of pistachio is under practice from the ancient times; in fact fragments of pistachio nuts have been found in Iran and Afghanistan dating from the sixth millennium BC (Saitta et al. 2011). The word ‘pistachio’ is derived from ‘pistak’ which is a word in the Avestan, an ancient Persian language. It was first cultivated widely in the Persian ancient empire, from where it is believed to be expanded gradually to the west. From the history, it has been known that the Empress of Sheba had forbidden commoners from cultivating and growing the nut for personal usage and declared pistachio as an exclusively royal food. Pistachios were first introduced in Rome in the first century AD as prized nut. The *Pistacia* species have been explored as a dyeing agent and as folk medicines in the ancient times as remedy for a variety of ailments (Gentile et al. 2007) varying from liver sclerosis to toothaches. The high nutritional content and storage life stability have also made pistachios a vital weightless food commodity between traders and explorers earlier.

### 25.1.2 Botanical Description

Pistachio is the only commercially edible green nut enclosed in a woody outer covering among the total 11 species in the genus *Pistacia*, while others all exude resin. Pistachio is by far the supreme economically vital tree nut which is a member of the family *Anacardiaceae*. Cashew, pepper tree, mango, poison ivy, poison oak, sumac and mombins are some of the other vital members belonging to this family.

Pistachio tree varies from small to medium in size and have the potential to extend as long as 12 m in length, but in the period of cultivation they are usually smaller in size. Pistachio is a commonly known desert plant having great tolerance to saline soil. Pistachios grow well when water containing 3–4 mm soluble salts is used for irrigation. Leaves of pistachio are compound pinnate that usually contain three or five leaflets. The leaf shape varies ranging from oblong to ovoid having dark green colour on the above and below; it has a pale colour over the tips and complete margins. The pistachio tree flowering behaviour is dependent upon the locality of flowering that could be either steppe-forests or semi-desert. Before blossoming, differentiation of floral bud occurs, and the growth of shoot generally starts at the end of March and finishes between April and May (Kashaninejad and Tabil 2011; Crane and Iwakiri 1981). The axillary buds maximum of one or two located on the new growth are vegetative. The inflorescence buds enlarge during March, and the flowering usually takes place at the end of May, during which they are clearly larger than vegetative buds, and after a period of 3 weeks, they start to grow and finally differentiate.

The tree of pistachio is dioecious, meaning both the flowers male and female are located on different trees, and so the nuts are produced necessarily by both female and male trees. Around 13 primary branches are present on pistachio tree with every branch having 5–19 lateral flowers and 1 terminal. The flowers of pistachio are reported to be apetalous which consists of sepals about five in numbers. Five small stamens are present on male flowers, and a single tricarpellate is present on female flowers. The nectarine is not produced by female flowers, so therefore they are unable to attract bees, and the bees may be inclined for pollen towards male flowers, and thus ultimately the wind spreads the pollen (Kashaninejad and Tabil 2011).

The fruit of pistachio is a drupe, and its shape is oval. It is a single seed, covered under a thin, soft seed coat (testa) which is edible in nature, covered under an inedible hard and smooth shell (endocarp) that is again covered by the hull which is fleshy and also inedible. The hull is fleshy and thin which is of pale green colour with a blush of red colour during maturity. Naturally the pistachio's hard shell is beige in colour, but sometimes in commercial pistachio, the shell is dyed in green or even red colour (Sehitoglu et al. 2015). The colour of seeds varies greatly from light to dark green or even greenish yellow, and it is composed of dual cotyledons enclosed by a minor light coating. The loosening and easy separation of hull from the shell is the evidence of physiological maturity occurring in pistachio, and also during maturity, the colour changes from green to red (Crane 1978). The taxonomic classification of pistachio is as follows:

| | |
|---|---|
| Kingdom | Plantae |
| Division | Magnoliophyta |
| Class | Magnoliopsida |
| Order | Sapindales |
| Family | Anacardiaceae |
| Genus | *Pistacia* L. |
| Species | *Vera* |
| Common name | Pistachio |

### 25.1.3 Production

Pistachio (*Pistacia vera*) cultivation is majorly carried out in countries such as the United states, Iran and Mediterranean countries and also in the Middle East. The largest producer of pistachio in the world is Iran, contributing around 40% to the total production globally. The United States comes the second with 27% contribution to the total production globally. In 2019–2020, the worldwide production of pistachio was reported to be 655.2 thousand metric tons with the United States being the leading producer of pistachio in the world contributing around 51% to the world's overall production, followed by Iran contributing 31%, Turkey with 11%, Syria contributing 4% and then Afghanistan contributing 1%. Turkey acquired the third position (85,000 tons) in the list of annual pistachio production preceded by the United States (233,147 tons) and Iran (230,000 tons) in 2016. The United States and Iran are the largest exporter of pistachios in the world, exporting to various countries.

## 25.2 Antioxidant Properties of Pistachio

Antioxidants are those substances which, when added to foods containing lipid, enhance their shelf stability by limiting the process of lipid peroxidation, which plays a major role in the deterioration of food substances hindering their processing and storage (Goli et al. 2005). Synthetic antioxidants like butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) have been extensively used in various food products from centuries. However, these synthetic antioxidants have limited use due to their detrimental health effects and induce carcinogenicity (Mahdavi and Salunkhe 1995; Goli et al. 2005). Due to these reasons, attention has moved towards the search of antioxidants of natural origin, particularly of plant origin has remarkably enhanced in last few years. Natural antioxidants like polyphenols and flavonoids obtained from various plant parts have the ability to act as free radical scavengers and as singlet oxygen quenchers and metal chelating agents. Nuts such as pistachio have gain the attention of scientists and researchers based on the study on different parts which includes leaves, hulls, kernels and pistachio gum as they possess antioxidant, anti-inflammatory and antimicrobial properties.

Pistachios are considered as an abundant source of phenolic compounds and therefore are regarded as 'unique functional food' and have been placed recently in the list of 50 foods that are rich in antioxidants (Halvorsen et al. 2006). The phenolic substances found in pistachios like anthocyanins, proanthocyanidins, isoflavones, stilbenes, phenolic acids and flavonols are recognized for their high antioxidant capacity (Tomaino et al. 2010) and also for their chemopreventive, vasoprotective and cardioprotective capacities. These phenolic compounds including anthocyanins, due to which various fruits and drinks get their red colour, have anticarcinogenic, anti-inflammatory, antioxidant and antiangiogenic activities (Wang and Stoner 2008). Catechins present in tea aid effectively in the reduction of low-density lipoprotein (LDL) oxidation (Tomaino et al. 2010; Basu and Lucas 2007) and in

**Table 25.1** Antioxidant compounds detected in pistachios

| Nut part | Compounds detected | References |
|---|---|---|
| Hull | Different anacardic acids | Yalpani and Tyman (1983) |
| Kernel | Resveratrol | Tokusoglu et al. (2005) |
| Hull | Phenolic compounds | Goli et al. (2005) |
| Kernel | Violaxanthin, β-carotene, lutein, pheophytins, chlorophylls and neoxanthin | Giuffrida et al. (2006) |
| Kernel | β-Carotene, γ-tocopherol, β-tocopherol and δ-tocopherol | Kornsteiner et al. (2006) |
| Kernel and skin | Quercetin, naringenin, rutin, eriodictyol, apigenin and cyanidin-3-galactoside | Seeram et al. (2006) |
| Skin and kernel | Chlorophyll, β-carotene, cyanidin-3-glucoside and lutein | Bellomo and Fallico (2007) |
| Kernel | α-Tocopherol, proanthocyanidins, vitamin C, trans-resveratrol, γ-tocopherol, genistein and daidzein | Gentile et al. (2007) |
| Hull | Phenolic compounds and tannins | Bohluli et al. (2008) |
| Hull | Phenolic compounds | Rajaei et al. (2009) |
| Seed and skin | Gallic acid, phenolic acids, cyanidin-3-O-galactoside, catechin, epicatechin, eriodictyol, naringenin, quercetin, kaempferol, apigenin and luteolin | Martorana et al. (2013) |
| Hull | Phenolic compounds: phloroglucinol, gallic acid, sinapic acid, vanillic acid catechin and naringenin | Garavand et al. (2017) |
| Hull | Phenolic compounds | Ozbek et al. 2018 |
| Seed and meal | Procyanidin B1, gallocatechin, anthocyanins, flavonols, flavanones and gallotannins | Ojeda-Amador et al. (2019) |

the prevention of cardiovascular diseases. The antioxidant compounds detected in different parts of pistachio are presented in Table 25.1.

### 25.2.1 Antioxidants Present in Pistachio Skin

Pistachios are usually used after removing its skin, which is obtained from industrial processing of pistachio and is an important by-product. Several studies demonstrated that pistachio skins possess better antioxidant capacity in comparison with the seeds and the amount of total phenolic components is also much more in skins than in seeds (Tomaino et al. 2010).

### 25.2.2 Antioxidants in Pistachio Seeds

Over the past three decades, only limited research is available about the composition of pistachio seeds. Miniati (1981) reported an anthocyanin, cyanidin-3-galactoside, in the kernel of pistachio. On the other hand cyanidin-3-galactoside and cyanidin-3-glucoside were found in the skins and kernels by several authors (Seeram et al. 2006; Bellomo and Fallico 2007). Research conducted by Seeram et al. (2006) reported that anthocyanins particularly are found in the skin. In raw nuts, they have found 696 mg/kg cyanidin-3-galactoside and 209 mg/kg cyanidin-3-glucoside and in roasted nuts 462 mg/kg and 87 mg/kg, respectively. When the bleaching of nuts using hydrogen peroxide was done, it was observed that the anthocyanin levels decreased. The TEAC method was used to evaluate antioxidant activity, and the results showed that there was a correlation between the anthocyanin concentration and oxygen radical absorbing capacity. Bellomo and Fallico (2007) suggested that there was a relationship between ripeness and cyanidin-3-galactoside present in pistachio skin. Furthermore another research conducted by Wu and Prior (2005) established that anthocyanin is found exclusively in pistachios among other tree nuts. A research carried by Yalpani and Tyman (1983) indicated the presence of phenolic acids in the pistachio's external green-coloured shell. They reported that in dried shells of pistachio, anacardic acids (around 1.5%) also known as 6-alkylsalicylic acids is present. Goli et al. (2005) investigated the presence of total phenolics in the pistachio hull and suggested that the extracts of pistachio hulls can be used as alternative antioxidant source of natural origin. The reactive oxygen species (ROS) product detection was used in the assay of hypoxanthine/xanthine oxidase to evaluate the antioxidant properties of anacardic acids by Trevisan et al. (2006); they have observed that these substances in comparison to hydroxytyrosol or caffeic acid are more potent antioxidants. Some of the researchers reported resveratrol also known as trans-3,5,4'-trihydroxystilbene in kernels of pistachio (Tokusoglu et al. 2005; Gentile et al. 2007). Resveratrol has the potential to reduce chances of cardiovascular disease by obstructing or changing the aggregation and coagulation of platelet or modulating the metabolism of lipoprotein. The resveratrol content reported by Tokusoglu et al. (2005) was found to be higher i.e., 0.09–1.67 mg/kg, as compared with the results reported by Gentile et al. (2007) and Grippi et al. (2008). They have observed that the amount of trans-resveratrol-3-O-β-glucoside which is a glycosidic derivative was higher with a mean value of 6.97 mg/kg as compared to free resveratrol (Grippi et al. 2008).

Giuffrida et al. (2006) confirmed that violaxanthin, luteoxanthin, β-carotene, lutein and neoxanthin are present in pistachio kernels, whereas some of the authors confirmed the presence of only β-carotene and lutein (Bellomo and Fallico 2007). Giuffrida et al. (2006) suggested that the health beneficial effects of diets rich in carotenoids are attributed to their antioxidant capacity and also due to the presence of cardiovascular disease- preventing agents. Carotenoids are believed to be related with pistachio ripening, and the lutein concentration was found to be the highest in unripe pistachios which was 41.3–52.1 mg/kg, whereas 17.9–34.7 mg/kg concentration was observed in intermediate samples, and concentration of 18.1–37.7 mg/kg was observed in ripe samples by Bellomo and Fallico (2007). Also β-carotene level was found to be below 1.8 mg/kg. Similar concentrations of β-carotene and lutein were reported by Kornsteiner et al. (2006) with mean values of 4 mg/kg and 44 mg/kg, respectively. Higher concentrations of β-carotene were reported by Giuffrida et al. (2006) with mean value of 7.1 mg/kg, and intermediate levels of lutein were found with mean value of 29.14 mg/kg.

Tocopherols such as β, γ and δ were detected in pistachio kernels by Kornsteiner et al. (2006), whereas tocopherols α and γ were reported by Gentile et al. (2007). Tocopherols are also most popularly known as vitamin E, although it precisely referred to only α-tocopherol, which is regarded as the best antioxidant among all tocopherols. Tocopherols inhibit the process of lipid peroxidation which degrades both lipids and other neighbouring molecules like nucleic acids and proteins. According to Kornsteiner et al. (2006), the sum of both β-tocopherol and γ-tocopherol was found to be 293 mg/kg (average value), and the mean value of 5 mg/kg was observed for δ-tocopherol; however, these values were observed to be different in the samples evaluated by Gentile et al. (2007) for α-tocopherol (0.51 mg/kg) and γ-tocopherol (105.4 mg/kg).

Chlorophylls and chlorophyll-derived compounds were identified in kernels of Sicilian pistachio by Giuffrida et al. (2006). From this research, chlorophyll a, chlorophyll b and pheophytin have been reported to be present and their concentration found to be 54.14, 30.2 and 25.68 mg/kg, respectively. Bellomo and Fallico (2007) reported different amounts of chlorophyll a and chlorophyll b in pistachio kernels from different countries; the content of chlorophyll a varied from 18.3 to 150.6 mg/kg, and for chlorophyll b the amount varied from 7.1 to 49.7 mg/kg. The chemical structure of chlorophylls and related various molecules reveals the presence of a conjugated tetrapyrrole ring which provides the ability for absorbing light which is in turn associated with the colour and oxidative stability of the food items containing these pigments.

Some of the flavonoids were reported by Seeram et al. (2006) in the skin and kernel of pistachio. Among these flavonoids, two flavones (apigenin and luteolin), a flavonol and its derivative glycoside (quercetin and rutin) and two flavanones (naringenin and eriodictyol) were reported. They have confirmed that the presence of flavonoids is limited to the skins of pistachio with average values of apigenin found to be 0.2 and 0.03 mg/kg in skins and whole kernels; luteolin values found to be 10.0 and 1.04 mg/kg present in skins and whole kernels; naringenin values found to be 1.2 and 0.12 mg/kg present in skins and whole kernels; and 0.29 mg/kg quercetin found to be present in skins and whole kernels. Flavonoids such as rutin, naringenin and quercetin possess health beneficial effects, and naringenin is believed to possess antioxidant properties, act as a free radical scavenger and also protect DNA from in vitro oxidative damage (Moure et al. 2001).

Genistein and daidzein isoflavones were detected by Gentile et al. (2007) in pistachio kernel with the amounts 34.0 and 36.8 mg/kg, respectively. These isoflavones and *trans*-resveratrol are vital bioactive polyphenols and are known as phytoestrogens as they have the ability to interact with estrogenic receptors. Gentile et al. (2007) also detected the presence of proanthocyanidins and vitamin C with an average value of 34.8 mg/kg in pistachio kernels. Ascorbic acid have radical scavenging power and can neutralize various harmful radicals like glutathione, hydroxyl and peroxyl by hydrogen ion donation; proanthocyanidins have the ability to bind with metals via the process of complexation which involves its ortho-diphenol groups, thus suppressing the oxidation of lipid induced by metals (Moure et al. 2001). The 3-alkylphenols referred as cardanols, which are mainly monounsaturated were detected in pistachio kernels and the amount of these components was determined as 213.4 mg/kg. According to Trevisan et al. (2006), anacardic acids are much stronger antioxidants as compared to cardanols.

### 25.2.3 Antioxidants Present in Pistachio Hull

Different components of pistachio indicate good sources of bioactive components which have different positive health effects, including anticarcinogenic, antimicrobial, anti-inflammatory, antiangiogenic and antioxidant activities. Pistachio hull released from pistachio industries every year at the time of harvest is the largest by-product and can result in environmental imbalance. The hull of pistachio consists of great amounts of phenolic compounds as compared with the skins and is similar as those found in previously established sources of phenolic compounds. The dehulling of pistachio produces wastes and by-products in large quantities that are often discharged to fields and various orchards which raises serious concerns towards environmental safety. These wastes do contain some quantity of phenolic compounds with known antioxidant properties. Extraction of these phenolic compounds and recovery from dehulled waste may provide double advantage to both sectors, i.e. environment and nutraceutical. The external testa of the pistachio nut comprises about 40% of its weight.

Goli et al. (2005) reported that the green pistachio hull contains appreciable quantity of phenolic compounds in comparison with other sources which contain phenolics. They have extracted phenolic antioxidant from the hull using two different solvent extraction methods, i.e. one was solvent method, and the other was ultrasound-assisted methods using three different solvents, viz. methanol, water and ethyl acetate, and the results obtained were compared with the results of supercritical fluid extraction. Also, the effects of methanolic and aqueous extracts of pistachio hull on the soybean oil stability when heated at 60 °C were determined. It was observed that the pistachio hull extract effectively retarded the deterioration of oil at 60 °C, and its activity enhanced by increasing the concentration ranges between 0.02 and 0.06%. Furthermore, they have reported that at concentration of 0.06%, the hull extract had activity at par with that of BHT and BHA when they are added at 0.02%. Water extracts of pistachio hull were reported to contain high phenolic content, i.e. 32.0–34.0 mg/kg; hence the solvent extraction method using water or methanol can be regarded as efficient method for extracting phenolic compounds. These results represent pistachio hull as potential antioxidant-rich substance from which phenolics can be extracted easily, and usage of pistachio hull as a source of bioactive components may enhance the pistachio production value and recommend valorisation for a by-product which has no further use. Goli et al. (2005) suggested that hull extracts of pistachio possess appreciable antioxidant properties and could prove to be alternative sources of antioxidants derived from natural sources.

Garavand et al. (2017) studied the phytochemicals and radical scavenging activity of hull extracts of pistachio. The extracts using different solvents, viz. water, butanol and ethanol, were obtained and examined. They have observed that high-performance liquid chromatography-mass spectrometry demonstrated higher quantities of naringenin, catechin and vanillic acid in ultrasound-assisted extracts. Lately, microwave- and ultrasound-assisted extractions of bioactive components from various plant sources were studied by a number of researchers because of the speed and less time required for extraction, automation, efficient extraction and limited requirement of organic solvent (Taghvaei et al. 2013). According to them, ultrasound- and microwave-assisted hull extracts of pistachio increase the quantity of phenolic compounds extracted. The researchers have identified phloroglucinol and sinapic acid in pistachio hull for the first time with this research. They have not found resorcinol pistachio hull extracts obtained from any of the extraction method used by them.

## 25.3 Products of Pistachio

Pistachio nuts are primarily and most commonly consumed as a snack food in both raw and toasted forms and are also explored as an ingredient in confectionary industries for making bread, ice cream, fermented meats and sauces and in preparing pudding. For the preparation of many food items, pistachios are used after the removal of their skin. In industries the skin is removed from the nut which comprises about 10% of the total weight of the pistachios with shell. The high fat content of pistachios is considered as an unacceptable attribute, limiting its usage. The pistachio fat is regarded as healthy fat and is essential in some portion for the healthy well-being. The fat of pistachio is suitable for the need of the body; it has a very minimum content of saturated fatty acid and has a high amount of unsaturated fat. Pistachio nuts have a high content of protein (around 20%), which is actually higher than the protein present in vegetables. Pistachios are also high in fibre content, and intake of high fibre content reduces risk of various diseases such as bowel cancer. Today pistachios are explored by food industries due to the presence of these nutrients; they are also encouraged to manufacture food products based on pistachios. Pistachios enhance the overall product quality by adding colour, flavour and texture to the final product. Pistachios are easily available in the market in different forms and sizes which include whole kernels, sliced, in shell, diced (fine, small, medium and large) and slivered. Sliced pistachios are usually suitable for bakery products such as pastries, cereals or muffins. There are varieties of food products that have been prepared with pistachio and are rich in nutrients beneficial for human health. Some are listed below:

### 25.3.1 Pistachio Nut

Pistachio nuts are listed as one of the most nutritionally rich nuts in the world. They consist of a good amount of protein; dietary fibre; vitamins such as thiamine, vitamin E, vitamin K and vitamin B6; essential minerals like magnesium, phosphorous, calcium and copper; omega-3 fatty acid; and phytosterol (Shakerardekani et al. 2012; Rainey and Nyquist 1997). Various clinical and epidemiological surveys have established the potential health beneficial effects of pistachios and reported its ability to reduce unhealthy levels of cholesterol, serum levels of lipids, diabetes and coronary heart diseases (Rainey and Nyquist 1997; Jenkins et al. 2003; Sheridan et al. 2007). Due to these beneficial effects, pistachio represents as a potential ingredient for food industries for the development of a variety of new products.

Pistachio milk comes in the category of new products that can be prepared from pistachio. It can be consumed as a normal drink as other consumable vegetable milks or can be utilized as a base material in the preparation of other food products. For developing a new beverage using pistachios, various factors such as grinding of soaked kernels, blending time and pH of the slurry need to be considered (Shakerardekani et al. 2012). The flavour of the prepared pistachio milk was enhanced by adding salt, vanillin and sugar. According to a research done by Shakerardekani et al. (2012), the best pistachio milk was obtained with the milling of roasted kernels and mixing the paste with some amount of water and maintaining the pH at 8.5 for 30 min. This pistachio milk was prepared with small and unsplit pistachio nuts, those which are not considered for direct consumption of humans and can be used as a substitute for milk obtained from animal sources.

Ardakani et al. (2006) conducted a research on the optimization of process for pistachio butter production and studied the effect of mono-di glycerides and lecithin, the two widely used emulsifiers, with different levels on the leakage of oil and the effect of synthetic antioxidant (BHT) on the pistachio butter quality. The butter prepared was packed and stored for a period of 4 months at room temperature, and by using a measuring cylinder, the separation of oil was measured. The butter samples prepared with 2% mono-di glycerides and 2% lecithin showed a minimum oil leakage. Also, the addition of BHT antioxidant proved to be beneficial for improving the shelf life of pistachio butter.

Yuksel et al. (2017) carried out a comparative research on the physicochemical characteristics and sensory attributes of ice creams prepared with various kinds of nuts such as hazelnut, almond, walnut and pistachio. Ice cream is a complex colloidal frozen system, and it includes a lot of ingredients such as fat, milk, stabilizers, emulsifiers, fruits and flavouring agents. Ice cream is among those products which is relished and enjoyed widely by consumers of all parts of the world especially during summer season. Based on this, the production of various types of ice cream is of great importance. Therefore, functional and aromatic additives such as fruits and nuts are explored for ice cream production. The ice creams prepared with all the four nuts received good organoleptic scores and were highly accepted by the consumers. Incorporation of nuts in the ice creams enhances its nutritional value and also its taste and appearance as these nuts add their colour to the product.

### 25.3.2 Pistachio Powder

Alfonzo et al. (2019) conducted a research to study the impact of addition of pistachio powder on lysine-enriched bread. The study was conducted to study the microbiological, sensory and physicochemical characteristics of fortified pistachio breads. They observed that addition of pistachio powder does not have any effect on the biological leavening of the dough and also it reduced the height and softness of the final bread. The study revealed that the pistachio powder addition in the preparation of bread can prove to be a promising strategy to enhance the availability of lysine in cereal-based fermented products.

### 25.3.3 Pistachio Peel Extract

Pistachio peel contains a high amount of phenolic compounds which exhibit antioxidant activity and antimicrobial activity (Yazdi et al. 2020). According to the studies conducted, the most abundant phenolic compounds found in extracts of pistachio peel were phloroglucinol and gallic acid (Yazdi et al. 2019). Thus incorporation of pistachio peel containing these bioactive components to any food makes it a functional food. Functional ice cream was prepared by the addition of pistachio peel extract microcapsules (Yazdi et al. 2020). The antioxidant activity of ice cream enhances with the addition of pistachio peel extract to it. Additionally, the melting resistance, functional properties and first dripping times of ice cream were improved with the addition of pistachio peel extract to ice cream mixes. According to Yazdi et al. (2020), microcapsules of pistachio peel extract can be used as a potential ingredient which can be further explored for the value addition of ice creams to improve the functional properties of the finished product.

### 25.3.4 Pistachio Paste

Pistachio nut is very nutritious and popular among tree nuts. Roasted or salted nut snacks are prepared from split pistachios. The unsplit form is utilized for development of different products like pistachio milk, pistachio butter, pistachio halva, spread, etc. Nut spreads are product that contains a minimum of 40% nut ingredients that are added in different forms like paste, pieces or whole or slurry. The preparation process of nut spread is initiated by roasting and then grinding nuts to a consistency of a paste which has the ability to spread like real butter. The major components that are involved in making nut spreads are nuts, vegetable oil, sweeteners and some sources of protein such as whey protein or soy protein isolates. Pistachio spread was prepared by Shakerardekani et al. (2013) using pistachio paste as the major ingredient, and powdered sugar, red palm oil and soy protein isolate were used at different ratios. They observed that the best pistachio spread was one prepared without adding soy protein isolate and got the highest consumer acceptability score. Based on this research, they concluded that the most important attribute of spread to be accepted by the consumers was the high degree of spreadability and green colour which was due to pistachio's natural colour.

## 25.4 Health Benefits of Pistachio

Pistachio is a nut with health benefits and several other advantages and is a nut with different other antioxidants. This nut is nutrient rich with healthy fatty acid profile as well as protein, fibres and minerals such as magnesium and potassium and some essential vitamins such as vitamin K and tocopherol and several other phytochemicals. The presence of lutein and anthocyanin content in pistachio give its kernel unique green and purple colours. Pistachios have several health benefit effects, and when consumed in moderate amount, it can help in controlling body weight as they have satiation effects and also reduce net metabolizable energy content (Dreher 2012).

### 25.4.1 Effects on Blood Lipids

The consumption of pistachio had positive effect on blood lipids. Presently there are five randomized clinical trials published on pistachio nuts and its effect on blood lipids. In these trials, the test were subjected with normal to moderately increased levels of cholesterol, and pistachios were fed between 32 g and 126 g per day as part of their diets either free-living or controlled diets. Among the total five studies, four were found to have significant reduction in total cholesterol. The significant reduction in low-density lipoprotein (LDL) was observed by two of the studies, while the other three reported non-significant reduction. Two of the researches reported a significant increase in high-density lipoprotein (HDL), while the other three demonstrated no significant changes. Two of the five studies demonstrated significant reductions in triglycerides, while the other three concluded no significant reductions. Currently, two studies that have been conducted on secondary blood lipid measures provided additional information for the LDL lowering effect of pistachio after 3 weeks of its consumption. Altogether these studies suggest an overall positive effect of pistachio consumption on blood lipid profiles. Pistachios have the highest phytosterol content among the tree nuts with 61–82 mg of phytosterols per ounce. Phytosterols, which are structurally similar to cholesterol, interfere with dietary and endogenous cholesterol absorption.

### 25.4.2 Antioxidant and Anti-inflammatory Effects

Recent researches on pistachios suggest that it helps in improving antioxidant status and anti-inflammatory balance, which can improve cardiovascular health. Pistachios are one of the richest sources of water and fat-soluble antioxidants. Some of the clinical studies have shown that pistachios possess significant antioxidant effects. Two of the researches have reported that consumption of pistachios at 20% of the daily energy intake can enhance endothelium-dependent vasodilation and levels of superoxide dismutase and can reduce levels of serum interleukin-6 and lipid hydroperoxide significantly. Also, the intake of pistachio at same level can significantly enhance antioxidant potential and decrease malondialdehyde present in the plasma. The studies have found that diets containing pistachios can significantly enhance levels of plasma lutein and reduce concentrations of serum oxidized LDL as compared to the controlled diets that were without pistachio. The important phytochemicals in pistachios that can provide anti-inflammatory and antioxidant effects for maintaining good cardiovascular health are discussed below:

*Carotenoids*: Among all the colourful tree nuts, pistachio is the only nut containing significant content of xanthophyll carotenoid (Bolling et al. 2010). The primary carotenoid present in pistachio is lutein. Lutein is a xanthophyll carotenoid which is more polar than β-carotene with low ability to behave as pro-oxidant activity (McNulty et al. 2008). Lutein has been reported to help in reducing oxidation of small particle size LDL which might be because lutein is primarily transported within the HDL complex which is known for LDL targeted antioxidant activity. A randomized controlled feeding study have revealed that lutein of pistachios has potential antioxidant effects. When participants were given diets enriched with pistachio, the concentration of plasma lutein was found to be higher in them as compared with the basic diet.

*γ-Tocopherol*: The content of γ-tocopherol present in pistachios is 6.7 mg per ounce. γ-Tocopherol is a potent antioxidant and efficiently scavenges reactive nitrogen species and also has anti-inflammatory properties mediated through suppression of cyclooxygenase-2 (Dietrich et al. 2006). In addition, earlier studies have suggested that γ-tocopherol may work with aspirin synergistically to produce a stronger anti-inflammatory effect without any adverse effect on the stomach. The patients with coronary heart disease tend to have lower levels of serum γ-tocopherol as compared with healthy subjects.

*Phenolic compounds*: The total amount of phenolic compounds such as anthocyanins, flavonoids, etc. varies greatly among nuts, with pistachios, pecans and walnuts being the richest sources. The total phenolic content present in pistachios is about 470 mg per ounce. Phenolic compounds may possess some antioxidant and anti-inflammatory properties which can help in improving endothelial function and reduce oxidized LDL (Heiss et al. 2010).

### 25.4.3 Effect on Blood Pressure

Among the tree nuts, pistachios contain the highest potassium level up to 285 mg per ounce which is around 8% of daily value. Potassium is the vital intracellular cation in the body and is required for normal functioning of cells and maintaining blood pressure. Some of the clinical studies suggested that the increased potassium intake can help in controlling blood pressure in normal and hypertensive people (Khaw and Thom 2001).

### 25.4.4 Effect on Glycaemic Control and Type 2 Diabetes

Type 2 diabetes in people is prevailing worldwide and is a matter of serious concern. The prevalence of type 2 diabetes increases the risk of cardiovascular diseases to many folds especially for women (Barrett-Connor and Wingard 1983). Diabetes has been linked with a multitude of other health-related problems which include hypertension, blindness, limb amputation and renal disease (Giovannucci 2007; Xue and Michels 2007; Shaffer 2006). The addition of nuts in the diets of people who are suffering or are at the verge of developing type 2 diabetes can prove to be beneficial in regulating glycaemic control (Kochar et al. 2010; Casas-Agustench et al. 2011). Pistachio nuts are believed to have very low glycaemic index which varies from 4 to 9 (Dreher 2012). A clinical study recently reported that adding pistachios to foods with a high glycaemic index such as pasta, mashed potatoes and parboiled rice has resulted in the reduction of total postprandial glycaemic response by 20–30% (Kendall et al. 2011). This report suggests that incorporation of pistachios into diets with a high glycaemic index can prove to be beneficial in controlling blood glucose level.

### 25.4.5 Role of Pistachios in Controlling Weight

The growing problem of overweight and obesity prevailing worldwide is a matter of serious public health concern, as excess fat in the body increases the risk of various chronic diseases (Pi-Sunyer 2009; Mattes et al. 2008; Zhaoping et al. 2010). Several clinical studies suggest that moderate consumption of nuts may be helpful in providing people a healthy way to control their weight (Mattes et al. 2008). Pistachios when consumed as portion-controlled snacks may support in maintaining a healthy weight as compared to carbohydrate-based snacks for people on a calorie-restricted diet (Zhaoping et al. 2010). A randomized study based on reduced-calorie weight loss compared the effect of pistachios with pretzels. The study had 70 overweight and obese subjects who were given an afternoon snack of about 230 calories pistachios or pretzels for a period of 12 weeks. After the study, it was observed that both the groups lost their weights as expected, but the group that consumed pistachio lost more as compared to the pretzel group. It was also concluded additionally from the study that there was a significantly greater reduction observed in body mass index (BMI) as reduction of 4.3% in the pistachio group and 2% in the pretzel group was observed. The key mechanism of pistachios involved in weight control could be attributed to enhanced satiation and satiety signals and reduced metabolizable energy (Baer et al. 2012; Trivedi 2009).

### 25.4.6 Role of Pistachio in Preventing Cancer

Pistachios contain essential vitamins and vital micronutrients that have potential biological mechanisms of action which help in reduction of the risk of cancer, but the epidemiological evidence of pistachio reducing the risk of cancer in humans is still very limited. Recent researches showed that intake of nuts in diet such as pistachio proves to be beneficial in the reduction of cancer mortality and nuts can also protect from prostate cancer about 31% (Falasca et al. 2014), colon cancer in women, endothelial cancer about 27% (McGhie and Rowan 2012) and also breast cancer. However, it had a great effect on breast cancer post-menopause than pre-menopause.

It has been also suggested that consumption of pistachio produces more gut microbiota composition which in turn produces potential butyrate-producing bacteria as compared to almond consumption (Ghaseminasab et al. 2015), although the consumption of both nuts does not have any effect on the growth or activity of bifidobacteria. A research conducted by Wang and Dubois (2010) also suggests that intake of nuts such as pistachios in the diet increases the composition of gut microbiota. Many hypotheses explain the anticancer effects of nuts like pistachios which possess antioxidant and anti-inflammatory substances, thus providing growing evidence which indicates the major role of inflammation and oxidative stress in the progression of specific cancer types. Reprogramming of energy metabolism is considered as a main feature of cancer cells, and nuts like pistachios affect the progression of cancer cells as they have the ability to change cell metabolism and lipid profiles (Hernandez-Alonso et al. 2015).

## 25.5 Conclusion

The information outlined in this chapter provides information about antioxidant potential of different parts of pistachio such as seed, peel, hull, etc. and potential health beneficial effects of pistachio nut. Pistachios have been part of the human diet since ancient times and have been consumed by previous civilizations because of their high nutritional profile and health beneficial properties. Pistachios are rich in nutrients which consist of heart healthy fatty acid profile, dietary fibre, protein, potassium, vitamin K and a number of phytochemicals which include phytosterols, xanthophyll carotenoids and phenolic acids. The increasing number of clinical studies demonstrates potential health benefits of pistachio nuts. Various researches have suggested that pistachios have positive effect on blood lipid profiles and also help in the reduction of oxidative and inflammatory stress and in promoting cardiovascular health, appetite management, weight control and glycaemic control. The various antioxidant compounds found in different parts of pistachio nut such as seed, peel and hull have the potential to act as potent antioxidant and anti-inflammatory agents. The presence of phenolic compounds and antioxidants leads to health beneficial effects. Scientists have detected that consumption of pistachios can lead to the reduction of cancer and fatal diseases. The presence of these compounds has dragged the attention of food manufacturers, and they tend to explore this nut in a variety of different products such as spread, butter, milk, bakery items and so on. Over the last decades, researches have been focussing more on pistachio nuts because of the presence of several important bioactive components present in it for identification and improving their properties. The presence of these bioactive compounds in pistachio and the studies related to its health benefits should ensure its potential use as nutraceutical and can be explored for the preparation of food products by food industries.

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# Peanut

# 26

Hradesh Rajput, Deepika Goswami, and Gulzar Ahmad Nayik

**Abstract**

Peanut or groundnut (*Arachis hypogaea* L.) is a very useful oilseed crop which is commercially grown all over the world for oil production. Hence, from the peanut oil industry, a substantial amount of peanut meal is also obtained as a by-product. The meal is rich in protein and with highest content of arginine. Apart from protein, it also contains various functional components such as chemical, vitamins, and minerals which enhance its utilization potential as a functional food ingredient. Recently, peanut has also been reported to be an excellent source of phenolic acids, resveratrol, phytosterols, and flavonoids. The concentration of these bioactive compounds can be enhanced by certain processing methods such as roasting and boiling. The present chapter gives an overview of bioactive compounds present in peanut and their health implications.

**Keywords**

Peanut · By-products · Bioactive compounds · Functional ingredients · Health implications

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## 26.1 Introduction

Peanut or groundnut (*Arachis hypogaea*), belongs to the legume or "bean" Family (Fabaceae). Peanut crops standing at the fifth position for oil production after soybeans, cotton, rapeseed, and sunflower. It is considered a good nourishment source giving protein (26–28%) with essential amino acids, dietary fiber, minerals, and other nutrients along with healthy and quality vegetable oil (48–half), (Pasupuleti et al. 2013). In India, it is the 13th most significant nourishment crop with half of it is utilized as crude material for the nut oil extraction, 37% for dessert shop, and 12% for seed purposes. The vegetative piece of nut is a fantastic roughage for nourishing domesticated animals since it is wealthy in protein and has preferable satisfactoriness and edibility over different grains.

### 26.1.1 History

The arachos signifies "a weed" and hypogaea signifies "underground burden" or as such, a weed with natural items made underneath the soil surface. This yield is generally known by two names-groundnut or nut. The term "groundnut" implies the pods with seeds that grow underground; though the ramifications of "nut" is in light of the fact that this collect has a spot with the leguminous family which consolidates also various yields, for instance, peas and beans. For this crop, the term groundnut is utilized in many nations of Asia, Africa, Europe, and Australia, whereas it is regularly alluded to as "nut" in North and South America. The phrasing of nut is used due to its uncommon developing propensity where blossoms are edged over the ground (soil) and after treatment, the gynoecium go into the dirt and builds units that contain seeds (portions). Right now, the term nut will be utilized due its more extensive acknowledgment.

The most punctual archeological records of groundnut or peanut in development are from Peru. The wild peanuts were developed at first. They were offered to the sun God as a major aspect of their strict ceremonials. And the nuts were used to be called as "ynchic." When Europeans arrived at the landmass, groundnuts were broadly scattered over South and Central America, presumably by the Arawak Indians. Hence, the European contact caused the wider spread of groundnut in world. Among the different types, the Peruvian sprinter type groundnut was acquainted for cultivation in the Western Pacific, China, Southeast Asia, and Madagascar. It was then moved to Africa by the Portuguese and later, by means of Brazil, it reached India. The Virginia type of groundnut arrived Southeast US, obviously, with the slave exchange. Gibbons et al. (1972) recorded generous auxiliary decent variety in Africa and Asia. The sorts they found and their areas upheld these different guesses with respect to dispersal. During the 1890s, nutty spread was made by the St. Louis specialist as the sensitive protein substitute for people with poor teeth. Joseph L. Rosen field authorized his creation to the lake organization, the creators of diminish dish nutty spread in 1928. Rosen field started developing his own image of nutty spread, which was the start and promotion of nutty spread in the America which bit by bit spread everywhere throughout the Asia and Europe.

### 26.1.2 Production

All inclusive, groundnut is developed in excess of 100 nations arranged in tropical, subtropical, and warm calm districts (Upadhyaya et al., 2012). China is the biggest producer and purchaser of groundnut on the planet with 166.24 lakh tons followed by India (68.57 lakh tons), Nigeria (30.28 lakh tons) and United States (25.78 lakh tons). Nut or groundnut is a noteworthy oilseed crop in India which has first situation in zone under development and runner up in the event of creation. As indicated by the fourth impelled assessments of Government of India, the production of groundnut was evaluated at 91.8 lakh tons in 2017–2018. The huge groundnut delivering Indian states are Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra, and Rajasthan. Gujarat is the major producing state speaking to 40% of all out national groundnut production. As indicated by the All India Crop Inclusion Report, GOI, as on September 20, 2018, groundnut was planted in about 40.13 lakh hectares land which was 3.25 percent lower than the relating time of a year ago (41.48 lakh ha). Among states, groundnut was majorly planted in Gujarat (14.67 lakh ha) followed by Andhra Pradesh (6.61 lakh ha) and Rajasthan (6.07 lakh ha).

Groundnut is a significant oilseed yield of India and furthermore a significant rural fare ware. In India, groundnut is produced in at least one season (kharif, rabi, and summer) and almost 80% of the yearly harvest originates from kharif crop (June–October). With a goal of evaluation of groundnut generation from kharif-2018 yield, a broad overview was attempted in five significant groundnut developing Indian states during the pinnacle collecting period. Among these, the best return of 2051 kg/ha was surveyed for Rajasthan followed by for Gujarat (1421 kg/ha), Maharashtra (1361 kg/ha), Andhra Pradesh (883 kg/ha), and Karnataka (750 kg/ha). The combined groundnut production from these five states was assessed at 43,47,298 MT, speaking to 83.6% of the surveyed national groundnut production. The most noteworthy production was recorded in Gujarat (20,84,780 MT) contributing 40.1% to the national production. Rajasthan was the second significant producer with 11,26,206 MT production and 21.6% commitment to national production. India also exports groundnut to different countries (Table 26.1).

### 26.1.3 Botanical Description

Peanut (*Arachis hypogaea* L.) or groundnut is a yearly herbaceous plant that has a place with the Fabaceae or Legume family. In spite of its name and appearance, the nut is not a nut, yet rather a vegetable.

| | |
|---|---|
| **Kingdom** | Plant |
| **Division** | Spermatophyte |
| **Subdivision** | Angiosperm |
| **Class** | Dicotyledonous |
| **Family** | Leguminosae |
| **Sub-family** | Papilionaceae |
| **Genus** | *Arachis* |
| **Species** | *Hypogea* |
| **Common name** | Groundnut |
| **Scientific name** | *Arachis hypogea* |

**Table 26.1** Top 10 groundnut importing countries from India (April–August, 2018–19)

| Importing countries | Quantity (metric tons) | Value (Rs. crore) |
|---|---|---|
| Indonesia | 9126.12 | 581.99 |
| Philippines | 22986.00 | 152.78 |
| Malaysia | 1339.86 | 89.01 |
| Algeria | 12746.00 | 86.65 |
| Vietnam soc. rep | 12903.00 | 85.72 |
| Thailand | 10207.00 | 69.93 |
| Ukraine | 5097.65 | 33.63 |
| Russia | 4163.55 | 26.35 |
| Netherland | 3198.00 | 24.03 |
| Nepal | 2841.11 | 15.70 |
| Top 10 total | 178608.29 | 1165.79 |
| Other countries | 22584.28 | 141.49 |
| Total | 201192.57 | 1307.28 |
| %share of top 10 countries | 88.77 | 89.21 |

Source: Directorate General of Commercial Intelligence and Statistics (DGCIS)

**Table 26.2** Common names of peanut

| Country | Common name |
|---|---|
| English | Peanut, groundnut |
| German | Erdnuss |
| Dutch | Pinda |
| Danish | Jordnod |
| Spanish | Panchitos |
| French | Arachide |
| Italian | Arachide |

It is known by different common names in different region as given in Table 26.2.

The peanut plant has procumbent stems and it grows to around 30–50 cm (1.0–1.6 ft) tall. Its leaves are alternate and compound, that is, the leaflets (ovate to oblong) are arranged on either side of the stem, typically in pairs opposite each other. The leaves are up to 6 cm long (2.25 inch) and each leaflet is 1–7 cm long and

1–3 cm across. Its five parted flowers are tubular, yellow in color with reddish veining, and self-fertile. After fertilization, the bloom stalks extend up to 6 cm long making it twist until the ovary contacts the ground. Further, tail development at that point push the ovary into the ground where the developed natural product forms into a vegetable case and consequently the organic product is required to be uncovered from the dirt for gathering. The organic product, an indehiscent vegetable, regularly contains 1–3 delicate seeds (in some cases, upwards of 6) which are separately secured with papery layer. These seeds contain up to 50% oil. The details of the leaf components, root, and seed components are as given here.

#### 26.1.3.1 Leaf Components

The plant leaf is involved a fingernail skin (peripheral tissue layer), the upper epidermis and the lower epidermis. The parenchyma cells involve the main part of leaf tissue. The xylem, present in leaf veins, transports water and supplements and stomata cells, present in the lower epidermis, store and discharge water into the environment.

#### 26.1.3.2 Root Components

The root arrangement of plants is comprised of basic roots, knobs. The principle branch root contains an external epidermis layer, inward endodermis layer of tissue, and the procambium that transports water into the plant and the meristem.

#### 26.1.3.3 Seed Components

The groundnut seed is comprised of an external most layer – pericarp which shields the seed from the outside components, the endosperm which is liable for the sustenance of creating plant, incipient organism, scutellum, the coleoptile – a sheath of material that helps the new plant in coming out through the dirt to the surface, plumule, and radicle.

## 26.2 Antioxidant Properties

The peanut contains various nutrients and phytochemicals which are distributed in different parts of the plant. The following Table summarizes the nutrients and phytochemicals present in plant, seeds, and leaves (Table 26.3).

The groundnut shell hemicellulose is comprised of D-xylose and D-glucuronic acid. The nuts include skin, body, and seed. Nut skin and body are obtained as a by-product of nut handling industry which are commonly utilized as animal feed and for compost purposes. The nut skin may be considered a source of phenolics and other phytochemical properties that have health promoting effects and hence may find practical nourishment applications (Yu et al. 2005). Likewise, the nut body has been found to be a considerable cancer prevention agent and display hostility to mutagenic impact (Duh and Yen 1997).

Groundnut contains different types of antioxidants which are located in the plant parts such as fruit, seed, and peel. These antioxidants help in protecting the body from

**Table 26.3** Distribution of nutrients and phytochemicals peanut plant

| Plant part | Chemical constituents |
|---|---|
| Plant | ***Acids:*** Caprylic acid |
| | Macro nutrients: Protein, fat |
| | Flavonoids: Quercetin, rutin |
| | Minerals: Magnesium, phosphorus, potassium |
| Seeds | ***Acids:*** Ascorbic acid |
| | Arachin |
| | Lecithin |
| | Macro nutrients: Protein, fat |
| | Minerals: Cadmium, zinc, cobalt, copper, iron, calcium |
| | Vitamins: Niacin, folacin, riboflavin, thiamine |
| Leaves | ***Acids:*** Arachidic acid, ascorbic acid, and beta-carotene |
| | Minerals: Calcium |
| | Vitamins: Niacin, folacin, riboflavin, and thiamin, |

oxidative stress that usually occurs in cases of various cancers and diseases. Several researchers have reported higher amount of antioxidant and phenols in peanut, and it has also been established that the roasting process could increase peanuts' p-coumaric acid levels, thereby could enhance their level of antioxidant. The roasted peanuts are as good in the antioxidant content. The seed contains various antioxidants such as p-coumaric acid, resveratrol, isoflavones, phytic acid, and phytosterols.

Peanut skin that constitutes around 3% of a peanut seed, are rich in antioxidants, particularly the phenolic compounds. It also contains another powerful antioxidant compound – resveratrol which is found in grapes and wine. This compound has shown its effectiveness in increasing endurance, reducing inflammation, and protection against the risk of heart disease. Roasting of peanut, unlike phenolic compounds, results in decreased resveratrol content. Processing and oil extraction from peanut leaves behind abundant amount of by-products, namely, peanut hull, peanut skin, peanut meal, and peanut vine. These are valuable sources of various bioactive compounds and hence may be harnessed for different food applications.

### 26.2.1 Peanut Meal

Globally, peanut is mainly produced for extraction of edible oil. The average world production of crushed peanut during 2000–2010 was about 14.09 million metric tons (FAS-USDA 2011). After oil extraction from peanut kernel, a by-product is left behind called peanut pulp and hence oil extraction of peanut kernel resulted into substantial quantity of peanut meal all over the world that is around 5.78 million metric tons during this period (FAS-USDA 2011). The oil extraction also results into an increase in the protein content of the cake which can reach up to 50% (Sales and Resurreccion 2009). The various oil extraction procedures for peanut have been reported by Yu et al. (2007). The "cold" and "hot" peanut meals are distinguished by the extraction procedures. A three-phase centrifugation extraction procedure gives cold peanut meal, whereas the hot peanut meal is obtained through two-phase centrifugation extraction procedure. The peanut meal obtained through cold crushing procedure, when compared with traditional oil extraction system (hot crushing), contains a lower oil and higher moisture content.

*Peanut Skin:* Peanut is commonly prepared for making nutty butter, cooked nibble peanuts, nut sugary treats, and nut oil portions. For this the piece is shelled which produces 3.5–4.5% of peanut skin. In world, around 0.74 million metric huge amounts of peanut skin is produced per annum as a result of the peanut handling industry (Sobolev and Cole 2003). A modest quantity of this result just is additionally handled for the extraction of polyphenolic mixes and the remaining is normally disposed of (Sobolev and Cole 2003). As peanut skin is wealthy in cell reinforcements, peanut skins as a cheap crude material for cancer prevention agent mixes for monetary just as natural advantage is the need of hour. In this manner, this significant side effect of peanut preparing industry can be transformed into a wellspring of bioactive mixes for additional usage as practical fixings in nourishments or dietary enhancements adding to the country's well-being (Yu et al. 2006).

*Peanut hull*: Peanut processing industry also gives another important by-product as a result of shelling that is peanut hulls to the tune of around 230–300 g of peanut hull per kg of peanut. This is the by-product of peanut. However, it also creates a significant waste disposal problem for such a huge quantity of agricultural waste. Hence, it demands a proper strategy for its disposal. It may be disposed through destructive techniques such as incineration. It is rich**er source of dietary fiber and other biologically active compounds. Converting this waste product of peanut processing industry into high value compounds however, is limited by some factors such as efficient and economic transportation**

## 26.3 Peanut Products

### 26.3.1 Peanut Based Imitation Dairy Products

Peanut helpful, scrumptious, solid, and reasonable four words not frequently utilized together. Be that as it may, stuffed inside these minor portions, you will discover the entirety of that and that is only the tip of the iceberg. Peanuts are the main expended nuts in the United States and thus, they can be found almost in any place. Hungry while you are getting things done.

### 26.3.2 Peanut Milk

Peanut was traditional prepared with the use of 1% $NaHCO_3$ according to Saio (1986) with slight adjustment. Peanut was washed with plain water and soaked in 1% $NaHCO_3$ for 16–18 h. Soaked peanut was boiled under autoclave for 3 min and de-husked. Later, the de-husked peanut was washed with water and ground with hot water (1:6 ratio of $H_2O$) in the processor. The slurry formed was sieved by muslin material and nut milk was produced.

### 26.3.3 Chocolate-Flavored Peanut Beverages

Two chocolate-enhanced nut refreshments, 100 l each, were readied. Every refreshment was made of 90.27% extricate, 8.35% sugar, 0.40% Recodan CM emulsifier, 0.39% Rom-Cacao enhance, 0.10% vanilla and 0.49% cacao powder. The drink was handled by the accompanying advances, and the concentrate was warmed to 65 °C in a steam-jacketed tank.

### 26.3.4 Peanut Curd

For the preparation of peanut curd, firstly we prepared peanut milk using standard method. After that, cultures of *Lactobacillus bulgaricus* and *Streptococcus thermophilus* were added in warm peanut milk and kept it for overnight, then we prepared peanut curd in the same manner as dairy curd (Jain et al. 2013).

### 26.3.5 Peanut Paneer

Autoclave is used for the blanching of peanuts. Subsequent to drenching, bits were de-husked and ground in high temperature water (1:6 proportion pieces to water) in the processor. The slurry formed was sieved by muslin material and the peanut milk was readied (Jain et al. 2013). Peanut milk was warmed at 80 °C and coagulated by 1% citrus extract. The coagulum was stressed through muslin fabric and the coagulum was gathered and squeezed for 30 min. It was then saturated with chilled water for 30 min.

### 26.3.6 Peanut Ice Cream

Peanut frozen yogurt blend arrangement arranged with "12% fat light simmered nut flour at 18% substitution" (P12L18) had the most elevated thickness (1080 cP) while "12% fat light broiled nut flour at 12% substitution" (P12L12) had the least consistency (272 cP). The control (chocolate dessert with 0% nut flour) test had a thickness of 636 cP. Consistency esteems are expanded with expanding the nut flour fixation. Level of cooking likewise had noteworthy impact on the thickness aside from 28% fat nut flour at 18% substitution. Increment in consistency with expanding nut flour substitution might be ascribed to the expansion in water retention limit of the dry blend.

## 26.4 Health Benefits

The groundnut is especially esteemed for its protein content (26%). On equivalent weight premise, groundnuts contain more protein than meat and around over multiple times more than eggs. The groundnut additionally contains nutrient E and limited quantities of nutrient B complex.

Eating peanuts has three principle medical advantages:

### 26.4.1 Supporting Heart Health

40gm of peanut-based product may improve the heart disease and lower the blood glucose level because it contains healthy mono and polyunsaturated fat than they do saturated fats.

### 26.4.2 Maintain a Healthy Weight

Peanuts are wealthy in fat, protein, and fiber. Eating them with some restraint may enable an individual to keep up a solid weight. Research Trusted Source found that ladies who ate peanut two times per week had a marginally lower danger of weight increase and obesity than the peoples who seldom ate nuts. An enormous scope study found that eating peanuts and different nuts may decrease an individual's danger of corpulence more than 5 years.

### 26.4.3 Managing Blood Sugar Levels

Peanuts are magnificent nourishment for people with diabetes due to low glycemic list (GI), which means nut does not cause huge spikes in glucose level. Nourishments with a GI of 55 or less as low-GI food sources, and those with a GI of more than 70 are high-GI nourishments.

- Research recommends that eating nutty spread can assist women with stoutness and type 2 diabetes hazard to deal with glucose levels.
- Peanuts are a decent alternative for individuals with diabetes hence. They are additionally a decent nibble choice for those hoping to lessen starches and increment stimulating fat admission.
- For their ideal medical advantages, pick crude peanuts with the skin on. Crude peanuts with their skin are high in cell-shielding cancer prevention agents.
- Roasted, nuts are high in sodium, which wellbeing experts connect to coronary illness. All things considered, eating broiled, salted peanuts as a feature of a fair eating routine is alright.

- As with most nourishments, the way to getting a charge out of peanuts is eating them with some restraint as a feature of a refreshing, calorie-controlled eating regimen.

### 26.4.4 Antimicrobial Activity

Compound 5, 7-dihydroxychromone (DHC) was found to repress the development of two pathogenic organisms *Rhizoctonia solani* estimations of 18 and 26μM, and radicle stretching of nut ED50 estimations of 65μM. DHC did not advance the development of harmonious nitrogen-fixing microscopic organisms; albeit related mixes did altogether expand their development rate. When added to high (10.0 g/L) mannitol medium, DHC at first restrained development; however, by 120 h after immunization, the development of all medications was comparable. These outcomes recommend a job for DHC discharged from nut shells in stifling pathogenic contagious contamination and contending plant development, yet not for *Bradyrhizobium* development advancement.

### 26.4.5 Antiviral Activity

Resveratrol substance is present in peanut. Resveratrol seems to repress viral disease/replication by managing fiery reactions and cell stress pathways, as opposed to cooperating straightforwardly with infection. To be increased explicit, resveratrol hinders initiation of the NF-kB pathway because of tumor necrosis factor (TNF), and builds enactment is a "key controller" of the fiery reaction. By repressing its actuation, resveratrol goes about as a mitigating. Since NF-kB is vital for proficient replication of a few infections, including Influenza A, HSV-1, and HIV-1, resveratrol is likely hindering viral replication when it represses NK-kB.

### 26.4.6 Antioxidant Activity

Cell reinforcement movement of the concentrates was tried utilizing ORAC and 2,2-diphenyl-1-picrylhydrazyl (DPPH) tests. Absolute phenolics were estimated utilizing the Folin-Ciocalteu strategy. The distinguished phenolic mixes were tested exclusively. The all out phenolic content was exceptionally corresponded with the cell reinforcement action of the ORAC and DPPH recommending that phenolic mixes may add to the cancer prevention agent movement. Mixes distinguished in the nut leaves and roots were phydroxybenzoic corrosive, caffeic corrosive, chlorogenic corrosive, ferulic corrosive (Ramarathnam et al. 1995).

### 26.4.7 Anticancer Properties

Peanut display a few physiological exercises remembering against malignant growth exercises for vitro and in test creature models, as well as in people. Anticancer movement of this compound is predominantly because of enlistment of apoptosis by means of a few pathways, just as modification of quality articulations, all prompting a lessening in tumor commencement, advancement, and movement. A defensive job of phytosterols (PS), particularly beta-sitosterol, is to defend from bosom malignant growth. The information proposed that peanuts and its items, for example, nut oil, nutty spread, and nut flour, are acceptable wellsprings of PS (Awad et al. 2000).

### 26.4.8 Reduce Cardiovascular Disease

Peanut use improves documents of cardiovascular infirmity chance in strong adults. Diets containing nuts reduction cardiovascular contamination chance parts. A comparable proportion of peanuts was incorporated during a 3-week choice diet or superseded a proportionate proportion of various fats in the eating routine during an 8-week replacement diet. Essentialness utilization from fat was extended through increasingly conspicuous affirmation of MUFA and polyunsaturated unsaturated fats, while drenched unsaturated fat confirmation remained commonly stable under all conditions. Regular nut usage cuts down serum TAG, grows use of enhancements related to lessened Cardio-vascular Disease (CVD) peril, and assembles serum magnesium center.

### 26.4.9 Other Uses

**Peanuts** Peanuts are healthy sustenances that have more than 30 supplements, elements, and phyto-supplements. All plant-based sustenances peanuts are regularly trans-fat have heart protective focal points (Kylenorton 2011). As a component of a collect turn program, peanuts can help with improving the soil. Peanuts are vegetables and can fix nitrogen in their hidden establishments.

**Leaf** Peanut leaves contain over 65% unsaturated fats including linoleic, palmitic, and linolenic acids; the assembly of oleic destructive is more in hydrated leaf cells. Undesirable amino should be removed from nut leaves for all intents and purpose, indistinguishable from that of practically identical concentrates got from other leaf tissues debilitated in sulfur containing amino acids.

**Oil** Nut oil gained by crisp crushing is used for therapeutic prescriptions. Nut oil is the purpose behind some remedial courses of action. It has skin progressing properties. Nut cake or nut oil supper is rich wellspring of proteins which are foul proteins. These foul proteins are used as dairy animals feed (ground-nut-oil-2013).

**Root**

1. **Use in Cosmetics:** The sogginess rich malignancy avoidance specialists found in the establishment of a nut plant are routinely found in cream conditioners considering the way that the caffeic destructive discovered inside the plant's fundamental establishments energize hair roots and defer skin adaptability.
2. **Use as Alternative Fuel***:* The base of the nut plant is plentiful in elements and malignant growth counteraction operators, yet, what is more in high-protein nut oil. The oil discovered inside the nut plant's establishments combines with other sustenance oils and a below average oil blend to make biodiesel fuel. Biodiesel fuel is decreasing the threat of turnpike impacts and super hot wrecks (Jenn Schanz 2013).

**Hulls**

Cancer prevention agents discovered normally in the nut shell help shield your body from parasitic contaminations and free radicals, which cause cell harm. Nut shells are utilized in the production of cleanser, beautifying agents, and flooring, in addition to other things. Nut structures contain a lot of vanillin. Nut frame is utilized to make hydrogen for fuel (Scott Roberts 2013).

**Storage** Peanuts can be saved for up to a year at whatever point set aside suitably. Rough peanuts should be taken care of in the ice chest in an immovably tied down holder to thwart weakening (Geetha et al. 2013). The peanuts should be taken care of in dull zones at low temperatures and relative clamminess. If the normal thing is being taken care of in a lone appropriation community along with usually created peanuts, mixing of the different attributes must be kept up a key good ways from.

## 26.5 Conclusions

Nut is one of the significant nut harvests of tropical nations, and it has a significant wellspring of palatable oil and vegetable protein. Peanut is a self-pollinated crop whereby blossoms are created over the ground, and after preparation, pegs move toward the dirt and are formed and created underneath the dirt. The dry spell inclined region of Anantapuram, the ranchers are mostly relying upon groundnut development. Because of the absence of water system, offices and poor option editing design in downpour bolstered territories like Anantapuram and in other Rayalaseema areas, the ranchers have been developing groundnut crop from the most recent a very long while. Yet, of nine oil seed crops developed in India, the territory under groundnut represents around 45% of the absolute trimmed zone and 55% of the all out oilseeds zone. India is the significant groundnut delivering nation on the planet. It stands at third spot in sending out groundnut and earned a measure of Rs. 52,579 lakhs during 2005–2006. The zone under groundnut in India shifted from 59,53,000 tons in 2002–2003 to 75,96,000 tons in 1996–1997 and its generation changed from 46,63,000 tons to 89,82,000 tons during the decade under investigation. Normally, the yield for every hectare in India was 1048.80 kgs. Peanuts comprise of 30 basic supplements and they are a decent wellspring of elements. Pharmacologically it is utilized as antimicrobial, antifungal movement, cancer prevention agent, anticancer, calming, hostile to hypertension, against mutagenic, reduce cardiovascular illness chance, amebicidal action, hypoglycemic, hypo-lipidemic impacts, and neuroprotective action. Nut oil is utilized as grease in nourishment industry and in corrective industry.

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# Raisin

# 27

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**Abstract**

Raisins are grapes which are in the dried form of different varieties of *Vitis vinifera* which are consumed all over the world. Raisins are rich in dietary fiber that has prebiotic effect. Raisins are an important source of many bioactive compounds such as phenolic compound and flavonoids polyphenols act as secondary metabolites in the biological activities of raisin. Phenolic acids, such as caffeic acid and coumaric acid, and the flavonoids such as quercetin and kaempferol have been identified in good concentration in raisins. The raisins work synergistically with fiber to maintain a healthy digestive system. Raisins are one of the best dry fruits for maintaining a good eye health benefit by protecting the cells from free radical damage. Oxidative damage and free radicals are risk factors for cancer, tumor growth, and aging raisin contain the good

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amount of antioxidants which defend the cell against free such radical devastation.

**Keywords**

Raisin · antioxidant · polyphenols · dietary fiber · health benefits

## 27.1 Introduction

Botanical name: *Vitis vinifera.*
Common name: Dry grapes.

Historically, raisins were accidentally discovered by humans in the early 2000 BC. Raisin is a word that came from the Latina *raceme* which means a cluster of grapes or berries (California raisins 2020). The sweet grapes that are dried in the sun and that shrivel up are called raisin. Until medieval times, raisins were the most-loved sweet after honey. Historians say that the ancient Armenians and Phoenicians had taken an initial step into impeccable viticulture, the process of grape growing (Winkler 1965).

**Since 900 BC**
The Phoenician started their colonial vineyard in Valencia and Malaga (Spain), and in Greece. Meanwhile, at the same time, the Armenians founded their vineyards in Turkey, Iran, and Iraq. Those places had spotless climate for making raisins and made a foremost market for the raisins. Historians believe that Currants – tiny seedless, tangy raisins – were planted in Corinth, Greece, hence the name (Vasilopoulou and Trichopoulou 2014).

Greeks traded with the Phoenicians and Armenians and the Romans consumed them in large quantities. Gradually, the popularity of the raisins grew with their value (California raisins 2020). Ancient physicians founded and treated with raisins for curing everything from the mushroom poisoning to old age.

**Eleventh Century** In the eleventh century, raisins were traded in Europe with the knights for their long travel as their most favorite one. A huge demand crisis occurred after that. The shipping techniques were improved for raisin to be sent to all the northern parts of Europe (Schönhärl 2013).

**Fourteenth to Sixteenth Century** In the mid-fourteenth century, raisins and currants played more important part in English cuisine, due to which they became very expensive.

In the sixteenth century, the viticulture spread to Germany and France. The English also tried to grow, but the climate was too cold and was not suitable for drying raisins (Winkler 1965).

In Spain, viticulture became popular; they made some more products like a variety of wines as dry table wine, sweet dessert wines, and Muscat raisins. In the Spanish conqueror's colonized Mexico, wine and raisins were familiarized soon.

**Eighteenth Century** In the eighteenth century, Spain passed on the knowledge about viticulture to Mexico in the colonizing time. They used it for the sacramental wines and grew the Muscat grape for raisin. In 1837, Spain turned to take power over the Mexican colonial government. They declined the mission system. In 1851, the Egyptian Muscat was grown near San Diego due to lack of water in San Joaquin valley where the climate was mild and there was extensive irrigation system for viticulture. In 1873, California's first raisin crops were grown by the people of California (Gray 2020). In 1876, English immigrants grew a seedless grape variety that was thin skinned, seedless, and sweet.

**Nineteenth Century** In the nineteenth century, California dancing raisin was introduced by California raisin industry. They raised marketing to increase awareness and demand for it.

Now the San Joaquin Valley in California supplies raisin for nearly half the world, making it the largest producer everywhere. Antarctica is the exceptional one in the world because of the cold climate region. April 30 became the national Raisin Day (Krosch 1989).

### 27.1.1 Production

The overall production of grapes in the world is 69 million tons presently (Table 27.1). India is the ninth largest producer of grape in the world with a production of 2,689,910 tons. India shares about 3.88% of total production of grapes in the world. In India, 78% of grape production is used for raw and fresh consumption (Christensen 2000). Only 17–20% of grapes are used to produce raisin and 1–2% are used for winemaking. The by-products made by grapes are raisin, jelly, jam, squash, grape juice, wine, tartaric acid, tannin oil, and cattle feed; the processed products such as wine, raisin, and grape juice are popular products all over the world from grapes (Sharma and Adsule 2007).

In India, raisins are mainly produced in the state of Maharashtra and Karnataka at places such as Sangli, Solapur, Nasik, and Bijapur. Indian raisins are available in different colors and sizes. They taste much sweeter than other types available form different parts of world. From 2012, the production of raisin in India has been increasing in the global industry. Marketing involves the movement very easily to consumers. From Sangli district, they send to Chennai, Mumbai, Delhi, and Kolkata markets (Gade 2018). Marketing of raisin is performed by different marketing channels or through cooperative societies or through private contractor forwarding agents.

**Table 27.1** Global production of raisins in the last 3 years

| | 2016–17 | | 2017–18 | | 2018–19 | |
|---|---|---|---|---|---|---|
| Country's | Production (MT) | Rs. (Lakhs) | Production (MT) | Rs. (Lakhs) | Production (MT) | Rs. (Lakhs) |
| Saudi Arab | 5061.98 | 5097.63 | 4103.00 | 4313.70 | 2822.03 | 4082.95 |
| Morocco | 361 | 323.96 | 496 | 494.56 | 1643.00 | 2568.38 |
| UAE | 2057.71 | 2480.09 | 2199.49 | 2658.84 | 1433.19 | 2480.74 |
| Sri Lanka | 1602.76 | 1232.19 | 1234.56 | 1112.51 | 1488.01 | 1828.53 |
| Vietnam | 243 | 248.34 | 799 | 985.25 | 856 | 1488.44 |
| Ukraine | 3905.50 | 2831.78 | 2870.00 | 1970.93 | 1311.00 | 1323.86 |
| Malaysia | 983.09 | 954.23 | 892.98 | 955.29 | 920.56 | 1314.71 |
| Indonesia | 258.31 | 268.38 | 1022.00 | 1079.52 | 794 | 1230.66 |
| Russia | 4185.60 | 3445.21 | 1673.12 | 1473.59 | 1023.00 | 1167.32 |
| Iraq | 1366.00 | 1209.41 | 1157.00 | 1213.62 | 607 | 753.71 |
| Nepal | 208.41 | 184.66 | 572.78 | 527.91 | 472.2 | 678.75 |
| Turkey | 133 | 119.05 | 382 | 520.79 | 459 | 675.01 |
| Brazil | 162 | 227.93 | 566.5 | 477.52 | 451 | 412.01 |
| Germany | 706.84 | 348.47 | 948.38 | 470.64 | 665.32 | 400.39 |
| Trinidad | 270.02 | 258.59 | 408 | 327.35 | 251.4 | 344.35 |
| Spain | 570 | 529.21 | 191 | 239.49 | 222 | 343.23 |
| Chile | 39 | 60.35 | 155 | 238.53 | 163 | 337.25 |
| Thailand | 145.9 | 162.77 | 133 | 165.98 | 172 | 306.29 |
| Qatar | 17.62 | 17.69 | 91.6 | 116.18 | 186.41 | 290.32 |
| Mauritius | 237.36 | 213.27 | 207.27 | 202.59 | 214.82 | 286.04 |
| Libya | 27 | 39.48 | 0 | 0 | 147 | 282.6 |
| Oman | 181.57 | 224.73 | 263.15 | 351.18 | 168.54 | 230.6 |
| Jordan | 96 | 107.06 | 76 | 98.87 | 123 | 196.5 |
| Poland | 1343.00 | 1028.89 | 473 | 330.43 | 190 | 195.82 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Romania | 437 | 361.79 | 251 | 285.14 | 132 | 187.04 |
| Mexico | 264 | 176.56 | 397.6 | 271.54 | 167 | 181.61 |
| Algeria | 0 | 0 | 82 | 130.99 | 98 | 179.5 |
| U K | 301.43 | 163.91 | 391.09 | 216.51 | 207.46 | 177.99 |
| Kuwait | 10.15 | 13.4 | 9 | 13.22 | 82.63 | 162.63 |
| Myanmar | 2 | 2.61 | 103 | 131.22 | 82 | 148.55 |
| Honduras | 140 | 96.27 | 199 | 139.72 | 117 | 132.44 |
| Singapore | 91.3 | 94.65 | 109.71 | 115.64 | 93.31 | 131.32 |
| Tunisia | 0 | 0 | 0 | 0 | 62 | 121.48 |
| Syria | 0 | 0 | 19 | 27.2 | 57 | 100.65 |
| Croatia | 720 | 590.67 | 266 | 190.29 | 76 | 86.55 |
| Serbia | 20 | 16.25 | 57 | 35.74 | 76 | 77.23 |
| Salvador | 60 | 42.53 | 98 | 68.11 | 58 | 70.12 |
| Iran | 280 | 274.19 | 125 | 146.17 | 52.02 | 66.35 |
| Egypt | 0 | 0 | 150 | 180.53 | 37.01 | 63.42 |
| Philippines | 392.14 | 182.93 | 356.06 | 156.2 | 61.68 | 50.22 |
| Guyana | 29 | 65.56 | 55 | 43.97 | 40 | 45.72 |
| Bulgaria | 333 | 218.21 | 307 | 83.32 | 143 | 45.62 |
| Lithuania | 1106.00 | 848.19 | 190 | 159.57 | 38 | 44.8 |
| Senegal | 112 | 91.02 | 19.02 | 17.15 | 38.31 | 40.91 |
| Fiji | 24.07 | 24.63 | 5.18 | 7.45 | 35.1 | 40.04 |
| Netherland | 142.01 | 79 | 107.23 | 61.8 | 58 | 39.75 |
| Albania | 0 | 0 | 33 | 30.91 | 37 | 39.6 |
| Australia | 13.02 | 28.23 | 25.32 | 56.93 | 14.42 | 38.87 |
| Bangladesh | 0 | 0 | 52.5 | 76.51 | 24 | 37.25 |
| New Zealand | 2.69 | 4.37 | 5.34 | 10.19 | 21.23 | 36.42 |
| Bahrain | 44.8 | 45.85 | 24.23 | 23.44 | 28.07 | 35.81 |

(continued)

**Table 27.1** (continued)

| | 2016–17 | | 2017–18 | | 2018–19 | |
|---|---|---|---|---|---|---|
| Country's | Production (MT) | Rs. (Lakhs) | Production (MT) | Rs. (Lakhs) | Production (MT) | Rs. (Lakhs) |
| Suriname | 19 | 16.45 | 0 | 0 | 25 | 35.37 |
| Peru | 18 | 28.33 | 71 | 110.88 | 19 | 33.3 |
| Maldives | 4.44 | 3.94 | 9.11 | 13.09 | 11.5 | 26.95 |
| Greece | 147 | 132.28 | 106 | 80.89 | 19 | 26.67 |
| USA | 7.94 | 23.18 | 9.59 | 26.42 | 6.56 | 25.96 |
| Georgia | 33 | 31.74 | 0.01 | 0.02 | 18 | 24.14 |
| Korea | 0 | 0 | 0 | 0 | 20.15 | 23.19 |
| Canada | 83.75 | 92.91 | 98.19 | 122.85 | 8.08 | 22.37 |
| Nicaragua | 40 | 28.21 | 60 | 40.32 | 20 | 22.33 |
| Belarus | 667 | 448.29 | 114 | 75 | 19 | 20.75 |
| Belgium | 95.02 | 76.77 | 82 | 59.11 | 18 | 12.03 |
| Japan | 4.85 | 6.72 | 4.97 | 6.14 | 4.17 | 7.69 |
| Kenya | 40.45 | 46.93 | 0.79 | 1.75 | 4.67 | 7.06 |
| Switzerland | 0.74 | 1.64 | 0.35 | 0.88 | 3.34 | 2.99 |
| Nigeria | 3.67 | 8.49 | 21.2 | 43.95 | 1.44 | 2.76 |
| South Africa | 0.86 | 1.3 | 0.36 | 0.58 | 0.63 | 1.83 |
| Uganda | 0.52 | 0.44 | 0.16 | 0.53 | 0.54 | 1.83 |
| Hong Kong | 0.85 | 1.31 | 0.31 | 0.64 | 0.57 | 1.67 |
| Seychelles | 0.99 | 1.32 | 0.39 | 0.72 | 0.67 | 1.63 |
| Togo | 0.24 | 0.24 | 0.31 | 0.36 | 0.64 | 1.34 |
| Brunei | 0.02 | 0.32 | 2.06 | 1.64 | 1.1 | 1.14 |
| China | 0 | 0 | 0 | 0.01 | 0.84 | 1.04 |
| Cameroon | 0 | 0 | 0.04 | 0.06 | 0.51 | 0.66 |
| Reunion | 0.5 | 0.48 | 0.25 | 0.48 | 0.3 | 0.64 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Cayman Is | 0 | 0 | 0.15 | 0.12 | 0.33 | 0.53 |
| Zambia | 0.05 | 0.14 | 0.2 | 0.41 | 0.16 | 0.52 |
| Taiwan | 0 | 0 | 0 | 0 | 0.3 | 0.5 |
| Rwanda | 0 | 0 | 0 | 0 | 0.11 | 0.42 |
| Malawi | 0.01 | 0.02 | 0.14 | 0.18 | 0.14 | 0.39 |
| Ghana | 0.09 | 0.2 | 0.16 | 0.4 | 0.1 | 0.28 |
| Congo D Rep. | 0.4 | 0.19 | 0.45 | 0.89 | 0.05 | 0.24 |
| Gambia | 0.14 | 0.13 | 0 | 0 | 0.17 | 0.22 |
| Madagascar | 0 | 0 | 0 | 0 | 0.04 | 0.21 |
| Macao | 0 | 0 | 0 | 0 | 1 | 0.2 |
| Gabon | 0 | 0 | 0 | 0 | 0.05 | 0.18 |
| Cote D Ivoire | 0 | 0 | 0.08 | 0.06 | 0.06 | 0.17 |
| Botswana | 0 | 0 | 0 | 0 | 0.08 | 0.15 |
| Congo P Rep | 0 | 0 | 0.1 | 0.18 | 0.1 | 0.14 |
| France | 0.1 | 0.07 | 0 | 0 | 0.03 | 0.13 |
| Papua New Guinea | 0 | 0 | 0 | 0 | 0.1 | 0.13 |
| Bhutan | 0 | 0 | 0.03 | 0.08 | 0.09 | 0.12 |
| Cambodia | 0.13 | 0.34 | 0 | 0 | 0 | 0.12 |
| Benin | 10.03 | 20.19 | 0.1 | 0.24 | 0.02 | 0.06 |
| Mozambique | 0.3 | 0.98 | 0.02 | 0.03 | 0.03 | 0.05 |
| Sierra Leone | 0 | 0 | 0.05 | 0.06 | 0.03 | 0.04 |
| Panama Republic | 0 | 0 | 0.02 | 0.05 | 0.01 | 0.03 |
| Pakistan | 9.52 | 11.74 | 0 | 0 | 0.01 | 0.02 |
| Belize | 0 | 0 | 0 | 0 | 0.01 | 0.01 |
| Portugal | 0.36 | 0.23 | 0 | 0 | 0.01 | 0.01 |
| Argentina | 18 | 25.65 | 41 | 55.2 | 0 | 0 |
| Armenia | 20 | 21.45 | 38 | 43.89 | 0 | 0 |

(continued)

**Table 27.1** (continued)

| | 2016–17 | | 2017–18 | | 2018–19 | |
|---|---|---|---|---|---|---|
| Country's | Production (MT) | Rs. (Lakhs) | Production (MT) | Rs. (Lakhs) | Production (MT) | Rs. (Lakhs) |
| Barbados | 37.2 | 30.84 | 19 | 13.65 | 0 | 0 |
| Bosnia-Herzegovina | 25 | 21.54 | 0 | 0 | 0 | 0 |
| Colombia | 19 | 11.85 | 0 | 0 | 0 | 0 |
| Czech Republic | 72 | 59.2 | 54 | 39.83 | 0 | 0 |
| Denmark | 2.1 | 0.65 | 0 | 0 | 0 | 0 |
| Djibouti | 0.6 | 0.73 | 0.5 | 0.37 | 0 | 0 |
| Finland | 0.01 | 0.01 | 0 | 0 | 0 | 0 |
| Guatemala | 38 | 30.36 | 0 | 0 | 0 | 0 |
| Guinea | 0 | 0 | 0.18 | 0.16 | 0 | 0 |
| Guinea Bissau | 0 | 0 | 0 | 0.01 | 0 | 0 |
| Hungary | 55 | 46.91 | 38 | 31.2 | 0 | 0 |
| Italy | 15.61 | 8.07 | 0 | 0 | 0 | 0 |
| Jamaica | 54.2 | 43 | 18 | 13.29 | 0 | 0 |
| Latvia | 128 | 97.7 | 0 | 0 | 0 | 0 |
| Lebanon | 19 | 19.28 | 38 | 54.6 | 0 | 0 |
| Liberia | 0 | 0 | 0.05 | 0.06 | 0 | 0 |
| Mali | 8 | 10.73 | 0 | 0 | 0 | 0 |
| Moldova | 93 | 75.67 | 0 | 0 | 0 | 0 |
| Netherland | 0 | 0 | 0.05 | 0.07 | 0 | 0 |
| Paraguay | 0 | 0 | 0.02 | 0.08 | 0 | 0 |
| Serbia | 49 | 34.87 | 57 | 39.26 | 0 | 0 |
| Slovenia | 3 | 2.22 | 0 | 0 | 0 | 0 |
| St Lucia | 0.01 | 0.01 | 0 | 0 | 0 | 0 |
| Sudan | 188 | 121.58 | 20 | 17.26 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Sweden | 27 | 29.26 | 0 | 0 | 0 | 0 |
| Tanzania Rep | 1.32 | 3.17 | 0 | 0 | 0 | 0 |
| Uruguay | 0.3 | 0.49 | 1 | 1.97 | 0 | 0 |
| Yemen Republic | 108.5 | 180.77 | 0 | 0 | 0 | 0 |
| **Total** | **30,859.10** | **26,895.72** | **25,259.50** | **23,904.65** | **18,926.46** | **25,910.56** |

Source: USDA (2018)

### 27.1.2 Botanical Description

The botanical name of Raisin is *Vitis vinifera*. Raisin has become a favorite food since 1490 BC because of their high micronutrient contents and nutritive value. Raisins are grown almost all over the world. There are various types of raisins found throughout the world. The production of it was surprisingly increasing gradually. Raisin contains the highest value of phenolic compounds and has high potential of damaging oxidizing agents in a living organism (Adam et al. 2016).

## 27.2 Antioxidant Properties

Antioxidants are found commonly in many foods and that help to prevent damages caused by the free radicals by neutralizing it. Antioxidants inhibit the oxidation reaction. Oxidation reaction can cause damage to the living cells. Antioxidants helps to neutralize oxidation reaction (Salah et al. 1995) which include vitamins, minerals, copper, selenium, and zinc. Raisins have many types: a few are seedless, golden seedless, raisins with seeds, sultana, Zante currant, and mixed species or varieties (Breksa et al. 2010). The antioxidant activity of raisin varies with different processing methods because phenolic compounds gets affected by different processing methods. The raisin extracts could be used as antioxidants is a food system. The higher amount of phenolic content in raisins helps in the antioxidant activity without negatively impacting sensory organs (Meng et al. 2011). Phenols, polyphenolics, and phenolic acid derivatives are most common antioxidant compounds, which are important for antioxidant activity (Karakaya et al. 2001). The flavonoids are also compounds of polyphenols. The flavonoids, free radical scavengers and enzyme inhibitors possess a good antioxidant activity (Mishra et al. 2010; Mnari et al. 2016). Phenolics are abundant in food materials. The phenolics are closely related to antioxidant activities, and phenolic acids and flavonoids present in raisin, such as benzoic and hydroxycinnamic acids, resveratrol, flavan-3-ols, catechin, and epicatechin, and flavanols, such as kaempferol, quercetin, myricetin, and anthocyanins, have potential antioxidant properties (Zhao et al. 2008). In raisin, the polyphenolic antioxidants play a major role in preventing cell damage. 2,2-Diphenyl-1-picryl hydrazyl assay [DPPH] is a common assay for screening of antioxidant activity, and other assays are CUPRAC (CUPric Reducing Antioxidant Capacity and PFRAP (Potassium Ferricyanide Reducing Power). The various parts of raisin that contain the antioxidant property are as follows.

### 27.2.1 Dry Raisin

The free radical assay is used to detect the antioxidant content. The different types of raisins were analyzed for the antioxidant activity by Kelebek et al. 2013. The types of raisin such as desert king, Muscat, red manaizi, wild redrose, blackcurrant, and seedless are primarily screened for the phytochemical activity. Studies have showed that desert king had highest content of phenolic compounds which indicated its antioxidant capacity (Kelebek et al. 2013). The red manaizi and wild red rose also contain more phenolic content and thus indicated the presence of antioxidants.

### 27.2.2 Oil

From raisin, the extracted oil has been examined, which shows the nature of lower molecular weight of phenolic acids such as caffeic acid, epicatechin, gallic acid, and protocatechuic acid which are found in highest amount in raisin oil. The resveratrol and kaempferol compounds have also been identified in the extracts (Zhao and Hall 2007). The low molecular weight flavonoids such as catechin and epicatechin could be more responsible for the antioxidant activity, but the high molecular weight flavonoids does not contain any antioxidant activity (Arts et al. 2000); thus, researchers say that in the oil extract of raisin only the lower molecular weight flavonoids were found to be more sufficient for antioxidants activity.

### 27.2.3 Raisin Seeds

The seeds of raisins have more lipid contents. The lipid peroxidation is the reason for the deterioration of food product. The addition of antioxidant is a method of increasing the shelf life. The synthetic antioxidants compounds, such as butylated hydroxy anisole (BHA) and butylated hydroxytoluene, are restricted in food uses (Jayaprakasha et al. 2001). Therefore, the search for natural antioxidants, especially of plant origin, has greatly increased. The seed extract shows the presence of monomeric flavanols and procyanidin components which could act with free radicals to make the stable product and eliminating free radical chain reaction (Adam et al. 2016). Thus, it could also contain efficient antioxidant activities.

### 27.2.4 Skin Peel and Juice

The peel of sultanas variety of raisins contain high content of reducing sugar and amino acids (Schuster et al. 2017). Raisins peels naturally contain phenolic compounds and thus have more antioxidant properties. The phenolic compounds which are in high quantity are procyanidins in skin (Zhao and Hall 2008). The juice of dry grapes contains highly efficient amount of phenolic compounds like catechin, ferulic, p-coumaric, and caffeic acids. Simultaneously, phenolic compound expresses the presence of high antioxidant activity (Papadakis et al. 2006).

## 27.3 Identification of Chemical Compound(s) Responsible for Antioxidant Proprieties and the Pathways Involved in the Biological Activities

In raisin, the phenols, phenolic acids, flavonoids, tannins, and anthocyanins play a major role toward higher antioxidant activity. They are radical scavengers because they are nucleophiles that act as inhibiting lipid peroxidation and chelators of metal ions that induce oxidation (Yeung et al. 2003). In the raisin extract, most of phytochemical compounds with antioxidant property can prevent cells from causing damage due to oxidation. A more number of phenolic compounds with different characteristics and functions have been detected (Kaliora et al. 2009). In the food content, the presence of phenolic compound causes different variations in organoleptic like bitterness and sourness in taste. The color of the particulate is also because of phenolic compounds and anthocyanins. The phenolic compounds are categorized into two groups as phenolic acids and flavonoids. (Reddy et al. 2005).

The most predominant phenolic compound in raisins is 3,4-dihydroxybenzoic acid. The dried raisins are rich in antioxidant polyphenols, minerals, fiber, sugar, and organic acid. The 2nd most abundant phenolic compound present is epicatechin. During drying process of grapes into raisin, due to enzymatic and air oxidation, there may be loss of phenolic compounds (Ouchemoukh et al. 2012).

Raisins contain resveratrol which possess antioxidant, anti-inflammatory, anticancer, and lowering blood cholesterol ability. The biological effect of raisin is particularly associated with procyanidins content for anti-inflammatory activity (Di Lorenzo et al. 2016). The diabetic activities were examined in the diabetic rats that were treated with the raisin seed extract; it indicated the lower mRNA level of pro-inflammatory mediator in comparison with non-diabetic rat as observed by Adam et al. (2016). The phenolic compound of flavan-3-ols and procyanidins is degraded in raisin because of its oxidative reaction. The degradation process occurs independently in the drying process. The improvement in seeds of raisin has been attributed to the process, and catechin, epicatechin, epicatechin-3-gallate, epigallocatechin-3-gallate, and procyanidins were undetectable in many varieties (Jayaprakasha et al. 2001).

## 27.4 Health Benefits

Raisins are dried grapes; they are indeed rich and contain numerous nutrientst. Further, raisins have a minor supply of carotenoids and xanthin. Raisins are more helpful and beneficial addition to the diet (Raisins Nutrition Facts 2020). The resveratrol is a phytochemical compound that is present in raisin which is also responsible for the anticancer and cholesterol-lowering activities. It is protective against colon and melanoma cancers and also against coronary heart disease [CHD] and Alzheimer's disease (Salehi et al. 2018). Raisins help to promote and aid digestion. Raisin that contains soluble fiber, helps to give the proper shape to stool as well, thus makes the passage of stool over intestines smooth. It improves digestion and regularity.

Raisins have oleanolic acid, one of the phytochemical compounds, which is essential for keeping the teeth safe from the decay, cavities, and brittle teeth (Zhang et al. 2013). They contain good amount of calcium and also prevent teeth from breakage and peeling off. The boron in raisin is good for maintaining the germ build-up in the mouth. The high amount of antioxidant in raisin helps to retain dermis follicle young and control the destruction against maturing cells. Raisins have more nutrients like zinc and selenium, which helps in the regeneration of skin cells (Schuster et al. 2017). Oxidative damage and free radicals are risk factors for cancer, tumor growth, and aging. In raisin, the nutritional antioxidants are essential and defend cells against free radicals' devastation.

One of the good health benefit of eating raisins is that they are good for eye health by protecting cells from free radical damage. It helps to shield the eyes against disorder like age-relevant degeneracy. The physicians noted that eating raisins regularly would help lower a person's blood sugar level (Kanellos et al. 2014). The raisin helps in reducing cardiovascular risk factors like blood pressure rate, and raisins have little sodium content and also consist of valuable origin of potassium, that aids blood vessels into recline. It contains beneficial amounts of minerals, such as iron, copper, magnesium, and potassium. It can promote equity of acidity levels in the stomach.

## 27.5 Conclusions

Raisin has attracted more and more attention because of their rich content of bioactive components and high natural antioxidant capacities. Different varieties have different requirements for raisin making. For raisin production, pretreatment is an important step to enhance the drying rate. Different pretreatments have an influence on grape quality, especially color, bioactive component, and texture. Therefore, novel pretreatment methods should be developed to improve the permeability of the grape skin without damaging the product attributes.

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# Cashew Nut (*Anacardium occidentale*) 28

Javid Ahmad Malik and Monika Bhadauria

**Abstract**

*Cashew* (*Anacardium occidentale L.*) is a versatile plant cultivated in several tropical countries. The crop is fast-growing, hardy, drought resistant, and it is familiar for its nut globally although all plant parts are valuable. It serves an immense importance with respect to global trade for its nuts. Although in the beginning it was considered a well-known agroforestry species used for the afforestation and soil binding purposes, its commercial exploitation started lately. Cashews are nutritionally very rich with a good fat and protein content. The main cashew-producing countries are Brazil, India, Mozambique, and Tanzania. Although cashew cultivation started in Brazil, it has reached to Asia, Africa, and Latin America. On global stage, India plays a major part on the cashew nut trade, being the second-largest country after Brazil for raw cashew nut production. The cashews are processed mostly through manual methods; however, some advancement in the methods has been achieved. Processing occurs through three main steps: drying, shelling, and then removal of testa. The fruit consists of cashew apple and cashew nut, which further consists of three parts: shell, coat, and nut. The increasing demand for the fruit owes to its beneficial uses of various by-products besides the nut. The fruit comprises many essential constituents which impart some essential roles to combat metabolic disorders, oxidative stress-induced manifestations, immune malfunctions, and cardiac dysfunctions.

**Keywords**

Cashew · Cashew by-products · Antioxidants · Immune malfunctions · Cardiac dysfunctions

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## 28.1 Introduction

| **Systematic Classification.** | Kingdom | Plantae |
|---|---|---|
| | Order | Sapindales |
| | Family | Anacardiaceae |
| | Genus | *Anacardium* |
| | Species | *occidentale* |

Cashew (*Anacardium occidentale* L) is a fast-growing, resilient, and drought-resistant plant species, which is cultivated in various tropical countries of the globe. It is commonly available valuable species in the world, with all parts of the tree are useful in one or the other way. It is at the 4-year-old stage when the tree starts producing fruits which reaches its highest production between 10 and 30 years. The trees are moreover utilized in the afforestation of barren, burned, coastal saline sandy lands and rehabilitation of tarnished lands.

The trees are vigorous, easy to cultivate, and require less care; however, the drawback for the plant includes its inability to stand extreme cold and frost for longer durations, reduction in the nut yield due to some fungal diseases, and the detrimental consequences of intense rains on the onset of flowering period. The cashew nut is considered as one of the valuable processed nuts on the global markets. It is variously named like "poor man's crop" and "rich man's food", wonder nut, and "goldmine" of the wasteland. The key commercial cash crop is indigenous of Brazil, and it was introduced by Portuguese traders in the late 1500s in India and Mozambique as a means of controlling coastal erosion. Spanish and Portuguese traders as well brought the species to Southeast Asia. The crop grows in about 30 countries with tropical climates, and India acts as the principal single producer.

### 28.1.1 Description of Fruit

The cashew nut is C-shaped and attached to cashew apple at its conically shaped lower portion. A shell lies on the outside of the cashew seed and an edible kernel on the inside. In the raw form, cashew kernel is soft, meaty, and white, which upon roasting changes its color and taste. Cashew is an excellent source of nutrition with respect to both cashew apples and cashew nuts. The cashew apple acts as a rich source of vitamin C, calcium, iron, and vitamin B1 than citrus fruits. The cashew nut shell oil is acidic and may cause skin burns upon its exposure.

Also the mucous linings of the gastrointestinal tract are affected in contact with oil extracted from shells or the exposure to fumes evolved during roasting. Cashews are utilized in confectioneries and baked goods and as health foods and breakfast cereals besides acting as adjuncts in chocolate manufacturing.

The edible nuts possess an immense therapeutic potential against various common serious diseases like anemia, liver ailments, urinary disorders, and diabetes. The medicinal role had widened to treat nervous illness and loss of appetite (Puranik, 2003). The therapeutic intervention of shell liquid is due to the presence of unsaturated fatty acids in it (Yang et al. 2009). Initially, the crop was considered suitable for soil conservation, afforestation, and also wasteland development, but then it gained commercial importance. In the initial years of cashew production in India, only cashew apple was treated as valuable; however, from the early part of twentieth century, commercial value of cashew kernel for export was realized.

## 28.1.2 Climatic and Soil Requirements

Cashew crops are legitimately tropical which grow in a wide range of climatic regions. A mean temperature of 25 °C is considered as optimal for cashew growth monthly; however, the fruit can withstand higher temperatures also. A yearly 1000 mm of rainfall is sufficient for the production, but a range of 1500–2000 mm might be taken as optimal. The tree is drought resistant owing to its well-developed root system. As for as the soil is concerned, the tree will not grow in poorly drained soils, so a well-drained sandy soil is recommended for its cultivation.

### 28.1.2.1 Production (India, World)

Cashew being an important commercial horticulture crop in India has the potential to provide livelihood for a number of rural people and generate employment opportunities. Majority of the workers working in the cashew industry are from the economically weaker sections of society, mostly belonging to backward communities. In this way, the cashew industry provides employment for lakhs of people in farms and factories, most of them from rural areas. Thus, cashew industry plays a chief role in social upliftment of the rural poor people, apart from its economic significance, that is why it is referred as "poor man's crop" and "rich man's food."

## 28.1.3 India in the Global Context

India is a key player in the world regarding cashew nut production. Although the cashew cultivation started in Brazil, its production occurs in many other parts of world: Asia, Africa, and Latin America. India's position itself is second in the worldwide production of cashews for area under cultivation as well as production, second only to Brazil. The prominent states in India dealing with the cashew nut production are Kerala, Goa, Karnataka, Maharashtra, Andhra Pradesh, Tamil Nadu, Odisha, and West Bengal. Among these states, Maharashtra tops the list with high production and productivity and Kerala has a long tradition in terms of both cashew cultivation and cashew nut processing.

### 28.1.3.1 Imports

India is not producing enough volume of raw cashew nuts as the processing sector demands; the import of cashew nut from other places like African and Southeast

Asian countries takes place. Cote d'Ivoire, Tanzania, Guinea Bissau, Benin, Indonesia, Ghana, and Mozambique are major countries from where import of cashews chiefly takes place. As a whole, cashew nut import from the African region in India's import contributed about 93% during the period. These imported raw cashews are usually exported back in the form of processed kernels.

#### 28.1.3.2 Export

India is the leading exporter of processed cashew nuts besides being one of the top producers of raw cashew nuts and the importer of raw nuts. However, India's share in the international market declined both in terms of quality and quantity due to entry of some new countries as exporters especially Vietnam.

India is the leading single producer, while West Africa—chiefly Ivory Coast, Guinea-Bissau, and Benin—is the prime regional producer of cashew nuts. The other major sources of production include Vietnam, Brazil, and East Africa. In Southeast Asia, Indonesia has now been a major producer and exporter of cashews. The cashew nut industry is a vital foreign exchange earner for various African countries and a source of employment for rural communities. There is a growing demand of cashews in Europe, America, and other regions of the world. The principal consumers of the cashews are the United States, the European Union, India, China, and Japan, India being the largest producer, processer, exporter, and consumer in the world (Patil 2017)).

## 28.2 Processing

Various traditional practices have been utilized for cashew nut processing by experienced workers in cashew-producing countries, especially in India, the world's largest producer of cashew kernels. The aim of the processing is to take out the kernel from the raw nut in the shell. Processing can be divided into a series of steps.

### 28.2.1 Drying

A manual cleaning is done to eliminate unnecessary materials, such as sand, stones, leaves, and twigs before further processing. Then, nuts are soaked to avoid scorching while roasting. This operation (soaking–draining–drying) is carried out until a rough 9% w.b. of moisture content is achieved (Balasubramanian, 2001). Roasting allows the nutshell to be brittle and loosens it from the kernel. At the same time, cashew nut shell liquid (CNSL) is released from the nut. Roasting is mostly performed through open pan method, oil bath method, and drum roasting method. The outcome of roasting is evident in terms of texture, color, flavor, and overall appearance of kernels. Hence, it should be noted that the roasting method is a decisive of end-product quality.

### 28.2.2 Shelling

The next step is then parting of kernels from the unshelled kernels and shell pieces, which can be done either by hand picking or using mechanical blower. The obtained kernels are then passed through successive phases of drying and cooling in order to make the testa brittle. During these phases, the moisture content of the kernel has been found to reduce from 7% to 3% w.b. (Mandal 2000).

### 28.2.3 Removal of Testa

In this step, the testa is peeled either manually or mechanically. Moreover, the testa peeled off has also been known to be a rich source of phenolic compounds (Mathew and Parpia 1970) and catechins (Trox et al. 2011). A significant antioxidant activity was also found to be attributed to ethanolic extract of testa (Kamath and Rajini 2007). Then, the kernels are sorted into whole, broken, and splits, and final grading takes place based on color, size, and other standards according to specifications of Cashew Export and Promotion Council (CEPC). The international nut price is dependent on the kernel size and the percentage of broken kernels (Nouwligbèto and Jèrôme 2003). The broken kernels have a lesser market price but with higher nutritional value and commonly applied in nut butter formulations of various products (Lima and Bruno 2007). The kernels are finally packed well in tins under vacuum.

## 28.3 Cashew Products

The three chief cashew products globally traded are raw nuts, cashew kernels, and cashew nut shell liquid (CNSL). Besides these three, cashew apple is also useful, but it is usually processed and consumed on local level, though the yields of the cashew apple are about multiple times higher the weight of the raw nuts. Raw nuts are the main commercial products of the cashew tree and are either exported unprocessed or processed prior to export.

### 28.3.1 Cashew Kernels

A comparatively higher percentage of cashew kernels are being used in the form of snacks, and the remaining percentage is utilized in confectionery. Cashew is being utilized in various purposes like breakfast, health food, salads, and baked goods. The cashews compete with other nuts including almonds, walnuts, hazels, pistachios, pecans, macadamias, and peanuts in the same market. The major factor which affects the cashew kernels consumption in world markets is their competition with other nuts.

The cashew is imported through contract by major importers based on the previous year's sale, so if the price of the product fluctuates too much, it is not being traded for fear of acquiring heavy losses. The year-to-year price fluctuation is oblivious as crop cultivation is not in an organized manner in most producing countries, in contrast to the almonds and pistachios which are grown in very organized manner and on large plantations, so their prices are not fluctuating year after year (Nair 1995).

### 28.3.2 Cashew Nut Shell Liquid

Cashew nut processing results in the production of an important by-product, cashew nut shell liquid (CNSL) increasing the added values to the cashew marketing. CNSL is highly heat resistible and thus consequently used in braking systems and paint industries. The liquid also possesses the compound *Anacardium*, which serves to treat multiple dermatological disorders. It is mainly traded in the United States, European Union, the Republic of Korea, and Japan markets comprising about more than 90% of world trade, mostly supplied by India and Brazil.

CNSL is dark reddish-brown in color and found in the pericarp of the nut. CNSL is a natural resin which could have the potential to act as valuable raw material for a myriad number of applications. Cashew nutshell, a by-product of the cashew nut processing, is an epithet of a valuable chemical, which acts as a raw material for petrochemical industry. Overuse of petroleum resources may result in rapid depletion of petroleum reserves. Thus, there is a need of an alternate option to maintain the living standard and continuation of industrial sector.

Cashew nut shell liquid (CNSL) is classified as oil, due to the elongated alkyl chains with variable degrees of unsaturation (Gedam and Sampathkumaran 1986), although it does not actually contain triglycerides (Akinhanmi et al. 2008). The liquid is dark brown, viscous, sticky substance (Salam & Peter, 2010), rich in polyphenols, and located between the two shells (inner and outer shells) of the cashew fruit. The liquid is proven to be toxic and corrosive (Akinhanmi et al. 2008); however, it serves as insecticidal agent for cashew nut right through the growth stages (FDA 2013). Moreover, CNSL has been seen to possess allergic reactions. Studies revealed that two chemical components, cardol and anacardic acid, present in CNSL, which are structurally similar to the one in poison ivy (urushiol), cause dermatitis in some individuals (Teuber et al. 2002). Cardol and anacardic acid in CNSL are known phenols and are found in 10:90 ratio (Gedam and Sampathkumaran 1986). CNSL has become an internationally important industrial commodity by being a component of paints, clutch facings, brake linings, electrical insulation, adhesives, and plastic (Gedam and Sampathkumaran 1986). Cardol present in CNSL is particularly painted onto furniture, books, and other stationary things for protection against insect destruction. Cardol may furthermore be used as a treatment option for leprosy and ringworm.

### 28.3.3 Cashew Apples

Cashew apples are the pseudo fruit of the cashew tree, which are pear-shaped, hard, nonclimacteric fruits. They become exceptionally juicy and fibrous upon ripening (Salam & Peter, 2010). In addition to being a good source of vitamin C (Assincao & Mercadante, 2003), they also possess higher levels of calcium, iron, and phosphorous (Salam & Peter, 2010). They can be consumed in various ways, either fresh or converted into other forms like juice, vinegar, wine, syrup, and jam. They are known to exhibit antioxidant activity (Shahidi & Tan, 2009).

### 28.3.4 Cashew Apple Juice

The cashew apple juice (CAJ) is a cashew apple product rich in vital nutrients, including amino acids, vitamin C, and anacardic acids. CAJ boosts body metabolism, antioxidant system, immune system, and cardiovascular activity during high-intensity exercise.

### 28.3.5 Industrial Applications of the Cashew Nut Shell Liquid (CNSL)

The CNSL acts as an important supply for biofuel and might be directly utilized in diesel engine (Vedharaj et al. 2014; Velmurugan et al. 2014). It has nonaggressive odor, low volatility, high boiling point (Mazzetto et al. 2009), good thermal insulation, and stability. CNSL-based resins are flexible and soluble in organic solvents (Sadavarte et al. 2009). Cardanol besides being an antioxidant is also used to reduce brittleness and thus consequently improving the blade flexibility (Blazdell 2013). Cardanol is also applied in the preparation of surfactants, nanotubes, gel, and nanofibers, which unlike carbon nanotubes provides a better opportunity for drug delivery (Balachandran et al. 2013). Both cardol and cardanol have been used as adhesives, plasticizer (Alexander and Thachil, 2010), fuel additive (Vasapollo et al. 2011; Suwanprasop et al. 2004), cleaning agents, and disinfectants for healthcare workers. Polymers and resin derivatives (Jaillet et al. 2014) can act as anticorrosion, flame retardants, waterproof, and surface-coating materials (Chuayjuljit et al. 2007). Furthermore, evidence revealed that the United States and Britain used CNSL as an insulator with high-voltage cables during the World War II (Gomes, 2010).

## 28.4 Chemical Composition

Cashews contain proteins (21.2%), fat (47%), carbohydrates (22%), and minerals (calcium, iron, and phosphorous) (Sharma, 2004) and release 575 kcal of energy per 100 g (Sathe, 1994). However, the nutrient content varies depending on the growing conditions (Nandi 1999). According to the USDA, they are viewed as equivalent to legumes, fruits, and vegetables in the Mediterranean diet (Dreher et al. 1996).

Cashew nut possesses many fat-soluble bioactive components. Besides monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs), cashews also contain a comparatively higher number of saturated fatty acids than other nuts like pistachios, pine nuts, and pecans (Ryan et al. 2006).

### 28.4.1 Lipid

The majority of the energy in cashews comes from their lipid content. The lipid composition of any nut is dependent on various factors like environmental factors, seed maturity, use of fertilizer, storage conditions, and seasonal effects (Alasalvar and Pelvan 2011), including saturated fatty acids (MUFA), glycerols, phytosterols, phospholipids, and essential oils (Alasalvar and Shahidi 2009). Linoleic acid and oleic acid are the chief fatty acids found in the cashew nut (Shahidi and Tan 2009).

Studies revealed that high temperature used during oil extraction from roasted cashews yields significantly higher amount than at low temperatures. This may be attributed to the fact that higher temperatures damage cell membranes and cause protein denaturization. However, the fatty acid profile of the extracted oil remains unchanged regardless of processing. Oil color evidently depicts the level of heat processing; the color deepens from light yellow to dark brown as the temperature increases. This is likely due to Maillard browning reactions that occur during heat treatment (Chandrasekara & Shahidi, 2011b).

### 28.4.2 Phytosterols

Phytosterols in humans lower LDL-cholesterol levels in the blood and also inhibit dietary cholesterol absorption in the gastrointestinal tract (King et al. 2008). Nuts and seeds serve as potent sources of phytosterols (Phillips et al. 2005). Cashews in comparison with other nuts have notably higher levels of phytosterols (Bolling et al. 2011), which has been reported to be 150 mg/100 g. However, the content varies depending on some factors, including environmental factors, use of fertilizer, and storage conditions that influence the fatty acid profile of cashews (Alasalvar & Pelvan, 2011).

### 28.4.3 Phospholipids

Phospholipids possess a vital biological role in maintaining cell membrane integrity, besides being used as emulsifiers (Angelova-Romova et al. 2013). Phospholipids have been disclosed and measured in cashews previously using various biochemical and molecular techniques. The four phospholipids which have been identified are phosphatidylcholine, phosphatidylethanolamine, phosphatidylserine, and lysophosphatidylcholine. It was further revealed that the fatty acid parts of the phospholipids were predominantly palmitic acid, oleic acid, and linoleic acid (Maia et al. 1976).

### 28.4.4 Proteins

Proteins are polymers of amino acids and are critical for the biological functioning of every cell in the human body (de Man et al. 1999). The proteins have many physiological roles, and they provide structure to almost every cell, mediate cell-to-cell signaling, help in nutrient uptake regulation, act as co-enzyme, stabilize nucleic acid structure, and help immune system functioning. Since nut proteins are considered as incomplete, although cashews contain some proteins, the quantity and quality are not optimal (Jones 1941). The crude protein amount present appears to vary greatly in cashew nuts.

Nandi (1999) reported that protein content may range between 13.13% and 25.03% in India. Ogunwolu et al. (2009) noted about 42% crude protein in the cashew kernel, comparable to the protein amount in peanuts. Cashews contain 36.6% crude protein as reported by Akinhanmi et al. (2008), while De Oliveira Sousa et al. (2011) reported 22.67 + 0.20% protein content in Brazilian Cerrado cashews. These differences in protein amounts could be attributed to the fact that methodology opted may vary, which was not reported for all studies.

The cashew proteins are like those of peanuts and soybeans in terms of functional properties, but have not yet become a typical functional ingredient in the food industry (Ogunwolu et al. 2009). Although cashews may serve potential use as functional food ingredients, it is quite important to note that they, along with peanuts and other tree nuts, are considered as leading causes of allergic reactions in humans, and it is therefore required by law to label any such with a warning statement (FDA 2014). The cashew-mediated allergic reactions can cause mild symptoms and in extreme cases death (Teuber et al. 2002).

### 28.4.5 Free Amino Acids

Free amino acids play a part in imparting flavor to selected foods. Its role in taste was discovered in 1908, when monosodium glutamate was found to be the key component of the umami taste of traditional Japanese seasonings. Since then, it has been discovered that all free amino acids contribute some flavor like sweet, sour, bitter, or umami to foods.

Till date, a minimal research has been done on the amino acids role in cashews. Previous studies have predicted the possible role of free amino acids in the development of sweet and roasted aromatic flavors. This is the particular area in future to be explored in depth involving cashew nuts (Pattee et al. 1995; St. Angelo et al. 1984). Furthermore, some studies have stressed on the possible involvement of hydrophobic D-form free amino acids in imparting the sweet taste of the nuts (Nishimura and Kato 2009) and of glutamine in umami taste of cashews (Kato et al. 1989).

### 28.4.6 Vitamins and Minerals

Cashews contain substantial quantity of vitamin E, iron, potassium, and magnesium (Akinhanmi et al. 2008; King et al. 2008). The role of vitamin E is as of a powerful antioxidant (Ryan et al. 2006), while magnesium and potassium maintain electrical balance in the nervous system (Akinhanmi et al. 2008). Moreover, lack of iron causes iron deficiency anemia (Nascimento et al. 2010). While taking into account the nutrient density of a food, nutrient bioavailability must be considered, which depends on intestinal absorption and its conversion to a biologically active form (Nascimento et al. 2010). It is difficult to measure bioavailability in vivo, as it refers to the concentration of a particular metabolite of compound at a target organ (Holst and Williamson 2008).

Not much research has yet been performed regarding the bioavailability of cashew nutrients. Studies also showed that an approximate 70% of iron and 75% of copper present in cashews are bioavailable (Nascimento et al. 2010). Furthermore, the crop contains phytate and zinc in a molar ratio of 22 (Harland et al. 2004). The mineral zinc contained in cashews may not be completely bioavailable, due to the presence of phytates (Hunt 2003). Iron in cashews as well is not completely bioavailable, again due to the presence of phytate as well as the oxalate content of cashews. The phytate and oxalate bind to calcium and iron in the GI tract and inhibit their absorption which can be of particular concern (McEvoy and Woodside 2010).

## 28.5 Antioxidant Properties

Reactive oxygen species (ROS) and reactive nitrogen species (RNS) are by-products of metabolism, exercise, and disease and associated with many adverse health effects (Kamath and Rajini 2007). They need to be quenched to avoid causation of too much oxidative stress on human tissue, which ultimately leads to inflammation, ischemia, carcinogenesis, and neurodegenerative disease (Blomhoff et al. 2006). Antioxidants manage oxidative stress-induced toxic manifestations, when they react with oxidants in a nonenzymatic way (Blomhoff et al. 2006). They act as scavenging agents of free radicals, chelating agents of pro-oxidant metals, quenching agents for singlet oxygen, and reducing agents. All food plants have been found to contain antioxidant compounds of varying structure. Antioxidants with different chemical structures can actually cooperate and behave in a synergistic manner (Alasalvar and Shahidi 2009). In this way, natural antioxidants present in fruits and vegetables could provide enough protection against health hazards mediated through ROS and RNS in the human body, especially when combined (Kamath and Rajini 2007). A number of nuts have been observed to be as rich sources of antioxidants (Blomhoff et al. 2006), in particular cashews, where the testa poses to be a source of high polyphenols concentration (Blomhoff, et al. 2006; Kamath and Rajini 2007; Trox et al. 2011).

Polyphenols are secondary metabolites with antioxidant capabilities (Manach et al. 2004) and characterized by aromatic structures with one or more hydroxyl groups attached, which are the basis of their free radical scavenging activity

(Manach et al. 2004). Studies have shown total antioxidant content (TAC) of cashews with testa as 0.388 mmol/100 g, which is quite comparable to that of almonds with testa (0.412 mmol/100 g) (Blomhoff et al. 2006). HPLC (High Performance Liquid Chromatography) analysis has revealed that the polyphenols responsible for the antioxidant activity in cashew testa are (+)-catechin and (−)-epicatechin. The levels found in cashew testa are higher than the polyphenol content of dark chocolate. It is also important to note that the research has been conducted principally on cashew testa, not cashew nuts, because of the presence of polyphenols in the testa, not the nuts, and of their less use (Trox et al. 2011). Cashew processing affects the polyphenolic content of cashew nuts, as the roasted cashews possess higher content than nonroasted ones. Interestingly, even the level of roasting effects the polyphenolic content, the higher the roasting temperature the more (Chandrasekara and Shahidi 2011a). In addition to polyphenols, α-tocopherol (vitamin E) is also seen in cashews, which is known for its powerful antioxidant capabilities and lipid oxidation inhibition properties. However, the quantity found in cashews is comparatively lesser than in most other nut types (walnut, pistachio, pecan, etc.) (Wagner et al. 2004). Recently, most nuts have been found to be exceptionally rich in antioxidants (Wu et al. 2004).

### 28.5.1 Oxidative Stress and Antioxidant Defense

Free radicals and other reactive oxygen and nitrogen species (ROS and RNS) are produced subsequent to normal cellular oxidative metabolic reactions. If these reactive species are not quenched by antioxidants, these cause damage to cells and the surrounding extracellular components by reacting nonenzymatically to them (Gutteridge and Halliwell 2000; Halliwell 1996; Beckman and Ames 1998). Oxidative stress is now thought to be the main cause for inflammatory diseases, acquired immunodeficiency syndrome (AIDS), ischemia, cancer, organ transplantation, ulcers, and many others (Blomhoff 2005; Gutteridge and Halliwell 2000; Beckman and Ames 1998; McCord 2000).

An central antioxidant defense mechanism comprises mostly of phase II enzymes, like catalase, superoxide dismutase, glutathione peroxidase, the glutathione S-transferase family, g-glutamylcysteine synthetase, and quinone reductase (McEligot et al. 2005; Talalay 2000; Fahey et al. 1997). Besides some well-known antioxidants like vitamin E, vitamin C, and selenium, there are various other antioxidants in dietary plants like carotenoids, which are most commonly found in the plant kingdom. Plant phenols act as antioxidants owing to the hydrogen-donating properties of the phenolic hydroxyl groups (Lindsey and Astley 2002). Though not in the top contributors of antioxidants containing foods, nuts have their own place. The TAC of most nuts contains much higher TAC values when compared to other antioxidant-rich animal-origin foods such as meat and milk, which contain 0.0–0.1 mmol/100 g (Blomhoff 2005).

### 28.5.2 Types of Antioxidants Found in Nuts and Their Roles

Almonds contain a range of flavonoids (Sang et al. 2002; Frison-Norrie and Sporns 2002), while peanuts and pistachios also contain various flavonoids and are rich in resveratrol (Lou et al. 2001). Walnuts contain a range of polyphenols (typically nonflavonoid ellagitannins and tocopherols) and tocopherols (Anderson et al. 2001). In cashews, an abundance of alkyl phenols has been found (Trevisan et al. 2006). Nuts possibly have protective effects on cardiovascular diseases via several mechanisms, which may be pointed to their fatty acid profiles, antioxidant contents, or a combination of these mechanisms. Various studies suggest some interesting biological roles especially against cardiovascular diseases (Mukuddem-Petersen et al. 2005). Almond pellicle contains flavonoids which act in cooperation with vitamin C and E as antioxidant defense. Hatipoglu et al. (2004) investigated the antioxidant potential of hazelnut oil, which was found to reduce cholesterol levels in given experimental animals.

## 28.6 Uses of Cashew Nut and Its By-Products

The cashew nut kernel consists of three different parts: shell, kernel, and the adhering testa. Kernel is the main portion of the cashew, which is the edible and is consumed in various forms. It is best sold as an appetizer to cocktail drinks and is part of the snack foods.

### 28.6.1 CNSL as Petrochemical Feedstock

Many phenolic constituents of CNSL impart innumerable versatile applications to it, which include insecticide, pesticide, brake linings, primers and paints, foundry chemicals, cements, and lacquers specialty coatings.

Anacardic acid, a major constituent of cashew nut shell, has been reported to provide much of the biological activities. CNSL is a blend of phenols with long-side-chain substituent enhancing its antioxidant activity. The cardanol-based porphyrin and their complexes cause photo -degradation of 4-nitro phenol in water, and the latter is toxic product disturbing ecosystem and human health (Vasapollo et al. 2011).

CNSL finds its applications in fuel blends and fuel mixtures (da Silva and de Matos, 2009), besides in the production of diesel oil. The versatile applications of CNSL lie in the fact that it is about 30–35 times more viscous than diesel. CNSL being a bioadditive increases the equipment durability and decreases the dependency on petroleum. It also acts environment friendly by decreasing pollutant residues released from fuel combustion products. The CNSL provides moisture damage resistance in the asphalts by preventing stripping, being an additive (Ribeiro et al. 2012). It has also been used in asbestos production, in addition to its extensive use along with cardanol in automotive brake-lining applications (Murthy and Sivasamban 1985).

Cardanol is useful in coating and resin industry as it provides outstanding gloss and surface finish to surface coatings with a high toughness and elasticity. Various products of utmost petrochemical values result upon pyrolysis of CNSL like tar, phenols, hydrocarbons, and gases (de Lasa and Afara 1995). More beneficial uses of CNSL like cholesterol lowering property owing to the presence of phytosterols have also been revealed (Andrade et al. 2011). Cardanol derived product cardanol polysulfide (CPS) has been used as a vulcanizing agent for natural rubber (Leerawan et al. 2005). The blend of cardanol-based novolac-type phenolic resins, with commercial epoxy or isocyanate monomers, produces thermoset polymers (D'Amico et al. 2009). Lasiodiplodin, a natural macrolide, which results from conversion of 6-alkenylresorcinols (CNSL-based cardols) possess antileukemic and plant growth-regulating features (Santos and Magalhães 1999).

Antioxidant and antiacetylcholinesterase activity of CNSL were also observed in strains of Saccharomyces cerevisiae (De Lima et al. 2008). A great antibacterial activity was also seen in CNSL attributing to the presence of anacardic acid (Eichbaum 1946). Anacardic acid and cardol were reported to possess antimicrobial (Kubo et al. 1993), antitumor (Kozubek et al. 2001, Kubo et al. 1993, Melo-Cavalcante et al. 2005), lipoxygenase (Ha and Kubo, 2005), and urease inhibitory activities (Kubo et al. 1999). Anacardic acid also kills gram-positive bacteria, which are the causative agents of many diseases like tooth decay, tuberculosis, acne, and leprosy (Himejima and Kubo 1991). Anacardic acid also acts as pro-apoptotic by reducing the expression of survivin (Sukumari-Ramesh et al. 2011). CNSL, cardanol, and cardol were far better to conventional solid and liquid fuels and are used by cashew nut and other industries as a fuel to reduce environmental pollution as it is renewable and has low ash (Gulati et al. 1964).

Due to depletion in petroleum resources, CNSL might be a wonderful potential raw material for polymer production (Bhunia et al. 1999). A wide variety of resins such as phenolic resins, epoxy resins, polyurethanes, acrylics, vinyls, and alkyds are synthesized from CNSL, owing to the presence of highly reactive long-chain, *m*-substituted phenols (Balgude and Sabins 2014). CNSL comprises of four major components: 5-pentadecenyl resorcinol (cardol), 3-pentadecenyl phenol (cardanol), 2-methyl 5-pentadecenyl resorcinol (2-methyl cardol), and 6-pentadecenyl salicylic acid (anacardic acid), which can act as better alternative for synthetic resins.

### 28.6.2 Environmental Impact

CNSL has not yet been revealed to possess mutagenic or carcinogenic activity although it might be a poor promoter of carcinogenesis (George and Kuttan, 1997). Besides that, the phenolic components present there pose several biological activities, like antioxidative properties (Trevisan et al. 2006; Façanha et al. 2007), acetyl cholinesterase inhibition, and membrane perturbation (Stasiuk and Kozubek, 2008; Stasiuke et al. 2008).

### 28.6.3 Cashew Apple Juice and Fat Utilization

An increased oxidation rate of glycogen and decreased rate of fatty acids occur during intense exercise (van Loon et al. 2001). Supplementation with cashew apple juice elevated lipid oxidation rates during high-intensity exercise (Prasertsri et al. 2013). The probable mechanism behind this effect of CAJ may be due to the role of vitamin C on carnitine synthesis (Johnston et al. 2006). Vitamin C serves as a cofactor for γ-butyrobetaine hydroxylase and ε-N-trimethyl-L-lysine hydroxylase enzymes, which are essential for carnitine biosynthesis (Hoppel 2003). Anacardic acids were also observed to pose same effect on body fat deposition. Moreover, vitamin C also reported to have a direct stimulatory effect on β-oxidation of fatty acids (Ha et al. 1994).

#### 28.6.3.1 Cashew Apple Juice and Oxidative Stress

Supplementation with CAJ elevated antioxidant potential such as superoxide dismutase activity and decreased inflammation in persons doing exercise. These particular factors increase exercise tolerance (Prasertsri et al. 2016). Vitamin C is a water-soluble antioxidant in humans; it copes with the free radicals generated during high-intensity exercise (Evans 2000). The vitamin C has been implicated in many processes linked with aging, inflammation, and cancer. Anacardic acids act as strong antioxidant (Trevisan et al. 2006); they suppress superoxide generation and thus ameliorate reactive oxygen species attack and protect DNA damage (Melo-Cavalcante et al. 2003).

#### 28.6.3.2 Cashew Apple Juice and Immune Function

da Silveira Vasconcelos and colleagues observed that CAJ optimizes balance between oxidative stress and antioxidant system by improving immunological mechanisms in rats (da Silveira Vasconcelos et al. 2015). Vitamin C supplementation increases the lymphocyte numbers in ultra-marathon runners after exercise (Nieman et al. 2002). Vitamin C acts as an immune system booster by maintaining an effective immune response (Wintergerst et al. 2007). Anacardic acids have also been observed to possess antioxidant potential as it increases heme oxygenase-1 activity, an antioxidant enzyme with many immune roles (Mancuso et al. 2007). Moreover, it may scavenge the ROS produced during intense exercise by maintaining the immune cell redox integrity (Wintergerst et al. 2006).

#### 28.6.3.3 Cashew Apple Juice and Cardiac Autonomic Function

A study revealed that CAJ at 3.5 ml/kg supplementation augmented parasympathetic activity at the time of intense exercise (Prasertsri et al. 2013). The vitamin C present in CAJ acts through a pathway, which is mediated by increased parasympathetic (vagal) and declined sympathetic activities (Park et al. 2009). Vitamin C supplementation enhanced vagal sinus modulation in patients with chronic heart failure.

## 28.7 Conclusion

The cashew crop is grown widely over the various parts of the globe. India contributes a major portion of the world's most cashew-producing countries. Cashew plays a role in agroforestry as well as in international market trade. Not only cashew nuts but all parts of the tree are useful in their own. The cashews are processed through three main steps before the final nuts come out for trade. The nuts possess some antioxidant and medicinal properties owing to the presence of some essential bio-constituents in it.

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# Hazelnut

# 29

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**Abstract**

Hazelnut belongs to the genus *Coryllus* and family *Betulaceae*. Hazelnut contains 10–22% carbohydrate, 1–3% cellulose and pectin, protein content of 10–24%, 50–73% fat and ash content of 2.4–2.8%. It is a good source of phytochemicals, fatty acid especially monounsaturated fatty acids, and fat-soluble bioactive compounds (tocopherol, phytosterols). It also contains essential amino acids, antioxidant phenolics, minerals, vitamins, and dietary fibers. These have ability to reduce risk of cardiovascular diseases, decrease cholesterol levels, and prevent metabolic syndrome. Major by-products of hazelnut (hard shells) are rich in phenolic compounds like catechin, epicatechin, epicatechin gallate, and gallic acid. Hazelnut may be consumed either naturally or in roasted forms. Roasting improves its texture, flavor, or color depending upon time and temperature.

**Keywords**

Hazelnuts · Roasting · Phytochemicals · Fatty acid · Antioxidants

## 29.1 Introduction

Nuts are considered to be a rich source of nutrients which contain high amount of lipids with health-promoting properties. Recently, nuts have been recognized as ‘heart healthy’ foods by USFDA, which has increased their demand to a large extent

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(Shahidi et al. 2007). Among the nuts, Hazelnut is an important nut crop grown across the globe. Common hazel (*Coryllus avellana*) belongs to the genus *Coryllus* of *Betulaceae* family. The plant is a shrub which can grow up to the height of about 15 m and is widely found along the coastal areas of Southern Europe and in Turkey (Del Rio et al. 2011). It is known by different names across the world. In Hindi language, it is known as "*Finda/Bindak*" while as in Kashmiri it is known as *"Wirni/Thangi."* Hazelnut is the popular tree nut across the world especially due to its pleasant flavor and the presence of phenolics/phytochemicals (Alasalvar et al. 2009; Chang et al. 2016). The health benefits associated with the consumption of hazelnut in humans are mainly because of its high content monounsaturated fatty acids – MUFA's (82–83%) and other lipid soluble bioactive compounds including tocopherol and phytosterols (Koyuncu et al. 2005). Hazelnuts are also a rich source of essential amino acids, phenolics (particularly caffeic acid), minerals like copper, manganese, zinc, iron, chromium, phosphorus, calcium, vitamins (A, B, C, K), betaline, choline, and, dietary fiber. A number of these compounds reportedly have hypocholesteromic ability, ability to reduce CVD risk, and to prevent nervous system disorders and metabolic syndrome (Feldman 2002; Mercanlıgil et al. 2007). Daily consumption of nuts including hazelnuts (42.5 g and 30 g) is recommended by FDA-Food and Drug Administration and EFSA-European Food Safety Authority for coronary heart disease reduction.

### 29.1.1 Historical and Present Day Cultivation and Usage

Hazelnut originated in the Mediterranean region. It is known since ancient times and has been used as food since preagricultural times. Hazelnut, due to its medicinal properties, has been used to cure various diseases and disorders, including chronic cough, sore throat, impotency and baldness. It has become now an important commercial crop across the world in various countries. Turkey is the main (largest) hazelnut producing country followed by Italy, USA, and Spain. The total world production of hazelnut (unshelled) was 863888 tons in 2018 (FAO 2020). Turkey produced about 515000 tons in the year 2018 and Italy produced about 132,699 tons/year in unshelled basis (FAO 2020). Besides this, other countries also produce with medium-to-low production. These include Spain, USA, Azerbaijan, China, Iran, France, Kirgizstan, Poland Georgia, and Croatia (Ciemniewska-Zytkiewicz et al. 2015). Turkey, the largest producer of hazelnut, accounts for about 70% of the world's total production (Beyer et al. 2002).

The main hazelnut varieties which are grown in Turkey are Ac1, Cavaca, Cakildak, Ham, FOSA, Kalnkara, Incekara, Kan, Minicane, Karafindik, Kargalak, Palaz, Kus, Sivri, Tombul, Badem, Uzun, Yassi, and Yuvarlak Badem (Ackurt et al. 1999; Ozdemir et al. 2001; Ozdemir and Akinci 2004). Among these, "Tombul" variety is known as Giresun quality or prime class and the rest of the varieties as levent quality or second class, although some of them are commercially important.

### 29.1.2 Botanical Description

Hazelnuts are also known as cobnuts and fiber nuts. Hazel belongs to the genus *Coryllus* and is placed in the birch family *Betulaceae*. Some scientists placed the genus in a separate family *Coryllaceae*. The genus *Coryllus* has about 15 species, which include *Coryllus avellana* L. (Hazelnut of commerce). Hazelnut plants are diploid ($2n = 2x = 22$). They grow either as a large tree or as shrub, generally up to the height of 2–5 m. Kernel, the edible portion of the seed is almost spherical or oval-shaped, about 1.0–2.5 cm long and 1.2–2.0 mm wide. The kernel is enclosed in a dark brown skin called as perisperm, which varies in thickness and appearance. The outer most part of the nut is a hard and woody shell which protects the kernel. During growth on the plant, the seed is enclosed in bristly leafy husk which opens in the autumn when complete ripening takes place (Contini et al. 2011). The deciduous leaves are round-shaped with a length of 6–12 cm. Soft hairs are on both the surfaces of the leaf blade and with serrated margin. Hazelnut flowers are monoecious and air-pollinated. The plants are shade tolerant, moderately deep-rooted and thrive best in well-drained soil.

### 29.1.3 Nutrient Composition

Hazelnuts are reported to be a good source of different health-promoting nutrients. The composition and micronutrient content of hazelnut is given in Table 29.1. The kernals have a carbohydrate content of 10–22%. It also includes a small quantity of organic acids. The predominant among them is malic acid. The nondigestible carbohydrates like cellulose and pectin are found at a level of 1–3%. The protein content has been found to vary between 10–24%. Kernels are also a rich source of fat, which is found at a level of 50–73%. The fat contains unsaturated fatty acids, namely linoleic, oleic, linolenic, spalmitic, and stearic acids. Mineral matter (ash) is reported to vary from 2.4–2.8% in different cultivars. Vitamins such as like $B_1$, $B_6$, niacin, and α-tocopherol are also reported in good amounts in hazelnut kernels. Hazelnut kernals also contain phytosterols. β-sitosterol is dominant (up to 90%), followed by campasterol (4%), and stigmasterol (2%). Bioactive substances like L-arginine, caffeic acid, gallic acid, epicatechin, sinapic acid, p-hydroxy benzoic acid, quercetin, and selenium which have health-promoting properties have been reported in hazelnuts. Energy value per 100 g of kernels varies from 600–650 kCal (Pourfarzad and Mehrpour 2017; Krol et al. 2019).

## 29.2 Antioxidant Properties of Hazelnut and Its By-products

Products obtained from hazelnut plants contain a number of phytochemicals and phenolic compounds which have significant antiradical (Shahidi and Naczk 2004), anticarcinogenic, antimutagenic (Surh 2003), and antiproliferative properties (Yang et al. 2009). These phytochemicals and phenolic compounds are associated with a

**Table 29.1** Composition and micronutrient content of hazelnut (per 100 g)

| Proximate | Dry roasted | Unroasted | Blanched/unroasted |
|---|---|---|---|
| Water (g) | 2.52 | 5.31 | 5.79 |
| Protein (g) | 15.03 | 14.95 | 13.70 |
| Total lipids (g) | 62.40 | 60.75 | 61.15 |
| Ash (g) | 2.45 | 2.29 | 2.36 |
| Carbohydrate (g) | 17.60 | 16.70 | 17.00 |
| Total dietary fiber (g) | 9.4 | 9.7 | 11 |
| Total sugar (g) | 4.89 | 4.34 | 3.49 |
| Sucrose (g) | 4.75 | 4.20 | 3.35 |
| Glucose (dextrose) (g) | 0.07 | 0.07 | 0.07 |
| Fructose (g) | 0.07 | 0.07 | 0.07 |
| Starch (g) | 1.10 | 0.48 | 0.93 |
| Energy (Kcal) | 646 | 628 | 629 |
| Energy (KJ) | 2703 | 2629 | 2630 |
| Minerals | | | |
| Potassium (mg) | 755 | 680 | 658 |
| Phosphorus (mg) | 310 | 290 | 310 |
| Magnesium (mg) | 173 | 163 | 160 |
| Calcium (mg) | 123 | 114 | 149 |
| Manganese (mg) | 5.550 | 6.175 | 12.65 |
| Iron (mg) | 4.38 | 4.70 | 3.30 |
| Zinc (mg) | 2.50 | 2.45 | 2.20 |
| Copper (mg) | 1.750 | 1.725 | 1.60 |
| Selenium (μg) | 4.1 | 2.4 | 4.1 |
| Vitamins | | | |
| Vitamin E (mg) | 15.28 | 15.03 | 17.50 |
| Beta tocopherol (mg) | 0.33 | 0.33 | 0.35 |
| Gamma tocopherol (mg) | 0 | 0 | 2.15 |
| Delta tocopherol (mg) | 0 | 0 | 0.14 |
| Vitamin C (mg) | 3.8 | 6.3 | 2.0 |
| Niacin (mg) | 2.050 | 1.800 | 1.55 |
| Pantothenic acid (mg) | 0.923 | 0.918 | 0.81 |
| Vitamin B 6 (mg) | 0.620 | 0.563 | 0.58 |
| Thiamin (mg) | 0.338 | 0.643 | 0.47 |
| Riboflavin (mg) | 0.123 | 0.113 | 0.11 |
| Folate (μg) | 88 | 113 | 78 |
| Vitamin A (μg) RAE | 3 | 1 | 2 |
| Vitamin A, IU | 61 | 20 | 40 |
| Beta carotene (μg) | 36 | 11 | 23 |
| Alpha carotene (μg) | 1 | 3 | 2 |
| Choline (mg) | N.R. | 45.6 | N.R. |
| Betaine (mg) | N.R. | 0.4 | N.R |
| Lutein + Zeaxanthine (μg) | N.R. | 92 | N.R. |
| Vitamin K (μg) | N.R. | 14.2 | N.R. |

Source: USDA, National Nutrient Database for Standard Reference, Release22 [2009]
*RAE* Retinol activity equivalent, *IU* International unit, *N.R.* not reported

reduced risk of different types of cancers, cardiovascular diseases (CVDs), coronary heart diseases (CHDs), stroke, inflammation, atherosclerosis, osteoporosis, and other neurodegenerative diseases caused by oxidative stress. The antioxidant activity of hazelnut is significantly higher when compared to peanut, walnut, and almond oils, but almost at par with extra virgin olive oil (Arranz et al. 2008). Antioxidant properties of defatted raw hazelnut kernel and its by-products (leafy cover, hard shell, skin, and leaf of the tree) using ethanol extraction were determined by different methods. These include total antioxidant activity (TAA) and free radical scavenging activity assays (2,2-diphenyl-1-picrylhydrazyl (DPPH), hydrogen peroxide and superoxide). Antioxidant activity was also evaluated in a β-carotene–linoleate model system, inhibition of strand breaking of supercoiled deoxyribonucleic acid (DNA), and inhibition of oxidation of human LDL (low-density lipoprotein) cholesterol. The results revealed that by-products of hazelnut had higher antioxidant activity as compared to hazelnut kernel. The antioxidant properties are due to the presence of phenolics, and hazelnut contains many of these compounds which result in potential antioxidant activity (Alasalvar et al. 2009). The major phenolic compounds present in hazelnut are flavan-3-ols and proanthocyanidins (Del Rio et al. 2011). Among tree nuts, hazelnuts are reported to contain the highest total proanthocyanidin content of 500 mg/100 g and a significant amount of hydrolysable tannins. Pevlan et al. (2018) detected 10 phenolic compounds in hazelnut using LCMS (Liquid Chromatograph Mass Spectroscopy). Six of these compounds were hydroxylated derivatives of benzoic acid (gallic acid, salicylic acid, protocatechuic acid, vanillic acid, and 4-hydroxybenzoic acid) and four were hydroxylcinnamic acid derivatives (caffeic acid, ferulic acid, o-coumaric acid, and sinapic acid). Skin of the roasted hazelnut has approximately 489–710 times more content of total phenolic compounds than the natural ones. This means that most of the phenolic compounds are present in the skin, which, however, is removed during roasting. It is important to mention that gallic acid is the most abundant phenolic acid which contributes to about 98.5% of the total phenolics found in the skin of roasted hazelnut (Pevlan et al. 2018).

## 29.3 Phenolic Compounds

### 29.3.1 Flavonoids and Related Compounds

Pevlan et al. (2018) identified eight flavonoids, out of which four (epicatechin-3-*O*-gallate, eriodictyol, isorhamnetin-3-o-ritinoside, and kaempferol-3-o-glucoside) were identified for the first time. Earlier, other flavonoids like quercetin, quercetin glucuronide, quercetin hexoside isomer, and quercetin-3-o-glucoside have been reported in hazelnut and its co-products (Chang et al. 2016; Del Rio et al. 2011; Tas and Gokmen 2015)

### 29.3.2 Tannins and Related Compounds

Extract of hazelnut skin are rich sources of tannins and include over 60% of total phenols found in nuts (Contini et al. 2008). Earlier, it was believed that tannins are anti-nutrients, but recently their effective antioxidant capacity and protective actions (like cardio protective, anticarcinogenic, anti-inflammatory, and gastroprotective) were detected which has led to rethink about their benefits in human health (Santos-Bugela and Scalbert 2000). Pevlan et al. (2018) for the first time identified five hydrolysable tannins and related compounds such as ellagic acid hexoside isomer, ellagic acid pentoside isomer, bis(hexahydroxydiphenoyl)-glucose isomer, flavogallonic acid dilactone, and valoneic acid dilactone in hazelnuts. However, ellagic acid, hexoside isomer, and ellagic acid pentoside isomer were detected in the free form in natural hazelnut, in the ester-linked form in roasted hazelnut and in the free and glycoside-linked form in the skin of roasted hazelnut. Some phytoestrogens including isoflavones and lignans were also detected in hazelnut kernel. These phytoestrogens have protective role against several diseases due to their potential antioxidant properties (Cornwell et al. 2004). Major phenolic compounds in hazelnut shells determined using high-performance liquid chromatography (HPLC) were catechin, epicatechin gallate, and gallic acid. Analysis of hazelnut shells by mass spectroscopy revealed the presence of 27 phenolic compounds, including coumaroylquinic acid, epicatechin gallate, gallic acid, quercetin, and six other phenolic compounds. Therefore, the phenolic extracts obtained from hazelnut skin being a rich source of potent antioxidants, can be used as a substitute for synthetic antioxidants in different food formulations for the development of novel functional foods (Contini et al. 2011).

## 29.4 Effect of Roasting on Hazelnut

### 29.4.1 Effect on Moisture, Water Activity and Color

Raw hazelnut kernels have average moisture content of about 4.6%. This has been reported for different varieties of hazelnut. However, moisture reduced significantly in hazelnut with the increase in the temperature/time conditions. Upon roasting for 30 min at 160 °C, water loss of hazelnuts was highest. Roasting also showed significant decrease in water activity. Color is an important indicator of level of roasting of hazelnuts. It is reported that brown pigments – melanoidins – are formed due to nonenzymatic browning reaction (Maillard browning reaction). In this reaction, reducing sugars and free amino acids or amides react to form melanoidins.

## 29.4.2 Effect on TPC (Total Phenolic Content) and Tocopherol Composition

Roasting temperature and time significantly affect the TPC and tocopherol content. Marzocchi et al. (2017) reported that high roasting temperature (160 °C for 20 min) increased the TPC and it was approximately 49.3% more than low roasting temperature (130 °C for 40 min) in hazelnuts. This could be due to greater matrix destruction at high temperature resulting in the more extraction of phenolic compounds linked to the matrix. The results obtained in this study varied from the reports of Pevlan et al. (2012) and Schmitzer et al. (2011) who reported lower TPC in hazelnuts after roasting. Schmitzer et al. (2011) reported that removal of skin and roasting at 140 °C for 15 min negatively affected the total phenolic content. Several other studies (Alasalvar et al. 2009; Shahidi et al. 2007) confirmed that the skin is a rich source of phenols and has positive role in the determination of total phenolic content. Roasting significantly decreased tocopherol content, and among tocopherols identified, α- tocopherol is less stable at high temperatures.

## 29.4.3 Effect on Microstructure of Hazelnut

Upon roasting, the texture of hazelnut attains a crispy and crunchy state, which strongly depends on changes in the microstructure. These changes depend on roasting conditions like temperature, air velocity, and roasting time, which gradually change the microstructure. This might be due to the separation of cell wall and formation of intercellular spaces, partial disruption of cytoplasmic network and swollen protein bodies due to denaturation of proteins during roasting. These changes in the microstructure of extremely liked quality of hazelnuts which were roasted at 165 °C for 25 min are beneficial in terms of increased consumer likability.

## 29.4.4 Effect on Proanthocyanidin Content in Hazelnut and Its Skin

Native (raw), roasted nuts, and roasted hazelnut skin extracts were evaluated using normal phase high-performance liquid chromatography so as to know the effect of roasting on proanthocyanidin content. The extracts were obtained with a mixture of acetone, water, and acetic acid in the ratio of 70:29.5:0.5, v/v/v and the hydrolyzed extracts were obtained by alkali extraction using 4N NaOH. Proanthocyanidins were then isolated from the extracts using Sephadex LH-20 chromatography with the elution of 30% methanol in water. Proanthocyanidins extracted from native hazelnut were 81% oligomers (4–9 mers) and polymers (≥10 mers). But, proanthocyanidins from roasted nuts were only monomers to trimmers. The reduction was attributed to loss of skin upon roasting. Proanthocyanidins extracted from roasted hazelnut residue, had lesser bound proanthocyanidins, than native (raw) hazelnuts. Roasted hazelnut skin had 21% bound proanthocyanidin mainly as dimers, trimmers, and tetramers and were recovered after alkaline hydrolysis (Lainas et al. 2016)

### 29.4.5 Effect on Nutrients

A study by Ozdemir et al. (2001) showed that roasting significantly affected thiamine, riboflavin, and total amino acid composition of hazelnut. It was found that riboflavin content decreased by about 30% in Akcakoca while in Giresun hazelnuts reduction was 18%. Thiamine was highly heat-labile and its content decreased by more than 50% upon roasting of nuts above 120 °C. Amino acid levels reduced with the increase in roasting temperature. Higher degree of roasting decreased peroxide value (PV) of Akcakoca hazelnuts, but there was an increase in free fatty acid content. PV of Giresun hazelnuts decreased on roasting at 158 °C or lesser, but increased significantly at higher temperatures. Increase in roasting temperature showed decrease in free fatty acid content of "Giresun" hazelnuts.

## 29.5 Health Benefits of Hazelnut

Consumption of hazelnut offers many benefits to humans in terms of maintaining their health. It contains fat (60%), proteins (15%), dietary fiber, vitamins, particularly alpha tocopherols, minerals, and essential amino acids. The hazelnut lipid fraction is rich in MUFAs (about 80% comprising oleic acid) and PUFAs, notably higher level of omega-3 and omega-6 fatty acids. MUFA-rich diet has been considered to reduce the risk of CHDs and has prophylactic effect against atherosclerosis. Among phytosterols, beta-sitosterol helps in reducing the levels of serum LDL cholesterol. Many research studies have reported that phytosterols act as protective agents against different types of cancer like breast, colon, and prostate cancer (Awad and Bradford 2005). Hazelnut skin, a rich source of phenolics, is considered as an excellent source of powerful natural antioxidants and may protect body from oxidative stress-related disorders like inflammation, diabetes, cancer, cardiovascular and neurodegenerative diseases.

### 29.5.1 Hazelnut and Obesity

Obesity is a complex disorder resulting from the deposition of excessive amount of body fat. Obese person has BMI-body mass index of 30 or more. Obesity is associated with the increased disease risk and other health problems which include hypertension, diabetes, and heart disease. Hazelnut-rich diet reduces the risk of obesity. Mollica et al. (2018) reported that incorporation of hazelnuts in high-fat diet significantly decreased the body weight of model animals (young adult mice weighing 15–18 g). The decrease in body weight was attributed to the fact that hazelnuts are rich source of protein and dietary fiber which increase satiety, thereby helping to reduce hunger pangs and thus making it easier to control the overall calorie intake resulting in weight loss.

### 29.5.2 Hazelnut and Cardiovascular Disease

Several epidemiological studies related to consumption of hazelnuts have reported that there is reduced risk of CHD, CVD, atherosclerosis, and other severe ailments besides lower plasma lipid profiles. Health claims related to the consumption of nuts and reduced risk of CHD have been endorsed by FDA (FDA 2003). Hazelnuts favorably change blood serum lipids of adult men with hypercholesterolemia, thereby having a positive role in mitigating CHD risk. A study by Mercanlıgil et al. (2007) showed that hazelnuts-enriched diet lowers risk of CHD. In this placebo-controlled study, 15 hypercholesterolemic adult men (aged 40–48 years) were recruited voluntarily and were given hazelnut (rich in MUFA) at the rate of 40 g/day for 4 weeks. This was followed by the measurement of total plasma triglycerides and high-density lipoproteinic (HDL) cholesterol, Apo A1, Apo B, and blood glucose concentration. The results showed that hazelnut-enriched diet reduced the concentration of plasma triglycerides, very low-density lipoprotenic (VLDL) cholesterol and Apo B by 31%, 29%, and 9% respectively. On the other hand, high-density lipoprotenic cholesterol increased by 12.6%, total cholesterol decreased by 5%, and low-density lipoprotenic cholesterol by 13.3%. However, changes were not observed in fasting blood glucose levels and Apo-A1.

### 29.5.3 Hazelnut and Alzheimer's Disease

Alzheimer's disease is characterized by the degeneration of neural tissues and is the most common reason of irreversible dementia (Reitz and Mayeux 2014). It is multifactorial disease caused by genetic and various environmental factors (Iqbal and Grundke-Iqbal 2010). Alzheimer's disease has been extensively studied but its pathogenesis has still not been clearly understood, and currently, no treatment is quite successful in practice for its control. However, loss of neurons and their dysfunction, senile plaques, and neurofibrillary tangles are the main features of this disease (Macdonald et al. 2014). The main hypothesis proposed for Alzheimer's disease includes amyloid deposition, tau phosphorylation, intracellular signaling impairment, oxidative stress, metal ion dysregulation, and inflammation (Webber et al. 2005).

Hazelnut is a rich source of nutrients and phytochemicals. Phytochemicals are reported to affect many pathways in Alzheimer's disease pathogenesis such as amyloidogenesis and oxidative stress in addition to some nontarget mechanisms like hypocholesteromic effect, anti-inflammatory properties and neurogenesis. A study conducted by Gojri et al. (2018) revealed that rats fed with diet containing hazelnut kernel (800 mg/Kg/day) led to significant improvement in memory and reduced anxiety. In addition to this, it ameliorated effect on neuroinflammation and apoptosis caused by amyloid-beta by lowering cyclooxygenase-2, interleukin-beta, and tumor necrosis factor. The possible reason could be that hazelnuts are nutrient dense and high in lipids with predominance of MUFA's and PUFA's among which oleic and linoleic acid are the major ones. Human brain is rich in lipids and PUFAs is considered necessary for its differentiation and development. Patients with Alzheimer's disease have significant problems in the regulation of unsaturated fatty acids metabolism. Alzheimer's disease brains have been reported to have significantly lower level of oleic acid (MUFA) in the frontal cortex and hippocampus. Oleic acid supplementation has been shown to reduce amyloid-beta levels in mice fed with diet free of cholesterol. Its supplementation has also significantly inhibited the activity of prolyl endopeptidase which increases in Alzheimer-affected brains. Phytosterols mainly beta-sitosterol have been shown to modulate molecular process involved in Alzheimer's disease, such as amyloid-beta formation via APP (amyloidprecursor protein) processing. Therefore, it may be concluded that hazelnut-rich diet has an important role in preventing the risk of Alzheimer's disease.

### 29.5.4 Hazelnut and Polycystic Ovarian Disease (PCOD)

Polycystic ovarian syndrome (PCOS) is an endocrine disorder common in women of reproductive age. It is characterized by irregular or no periods, hirsutism (hair growth in unwanted areas like face, chest, etc.), weight gain or occasionally loss, acne production, and problem with fertility. Besides, the women with PCOS may face other metabolic problems in later stages of life like type 2 diabetes, hypertension, depression, CVD, etc. The exact cause of this disease is not known but some factors play a role in its genesis. These include genetic and environmental factors. The disease results in the formation of small arrested antral follicles in the development process. Excessive insulin production due to insulin resistance, fall in levels of estrogen with increase in progesterone level and about three times increase in LH/FSH takes place in patients with PCOS (Maharajan et al. 2010). Demirel et al. (2016) conducted a study on three groups (six female rats in each group) of nonpregnant rats. The rats were fed with letrozole (1 mg/Kg body weight) once daily for 21 days to induced polycystic ovary syndrome. Following this, control group was given CMC (2 mL/rat/day), reference group (buserelin acetate; 20 mg/rat/week) and the treatment group (*Hazelnut oil* 2 mL/rat/day) for 45 days. The results showed hazelnut oil was effective in the treatment of polycystic ovarian syndrome *by* regulating gonadotropins, steroids, and serum lipid parameters. Besides, its potential antioxidant activity helps to regulate the disorder.

### 29.5.5 Hazelnut and Cancer

Cancer is an uncontrolled division of cells which results in tumors, damages immune system, and causes other impairments which can be fatal. In hazelnut, more than 100 compounds have been identified and classified as organic acids, phytosterols, triacylglycerides, tocols, phenolic acids, diarylheptanoids, tannins, flavonoids, lignans, isoflavones, terpenes, and taxanes. A study conducted by Gallego et al. (2017) found that viability of some human cancer cell lines reduced significantly with the addition of hazelnut leaf and stem extracts from three different hazelnut cultivars. The cell lines in this study were human cervical cancer cells, liver hepatocellular cells and human breast adenocarcinoma cancer cell lines.

### 29.5.6 Hazelnut and Reproductive Function in Males

Aging results in reproductive decline in males. This is due to the lack of balance between reactive oxygen species and antioxidant system of body (Leisgang et al. 2017). The imbalance in oxidant–antioxidant causes reproductive decline in males, and the organs and tissues of reproductive system get affected (Santiago et al. 2018). Lydeig cells which are responsible for testosterone synthesis decrease in number with aging leading to reduced serum testosterone (Ferrini and Barrett-Connor 1998). Hazelnut is a health-promoting food, as it is rich in nutrients and bioactives. These favorable nutrient profiles are considered important for male fertility (Colagar and Marzony 2009). Kara et al. (2019) studied the effect of hazelnut-supplemented diet in young and old male rats and found that consumption of hazelnut enhanced testicular antioxidant function and the quality of semen in young and old male rats.

## 29.6 Waste Utilization

Several hazelnut by-products such as leaves during harvesting, green leafy cover during shelling/hulling and skin are obtained during cracking and roasting process. These are commercially less valuable than hazelnut kernels. Hazelnut hard shells are the main byproducts of hazelnut industry and are rich in phenolic compounds especially (catechin, epicatechin, epicatechin gallate, and gallic acid). These shells are raw materials for the industrial extraction of natural antioxidants and for mulching in crop production. These are also used for the production of dye in the furfural industry.

Hazelnut meal obtained from oil extraction has high nutritive value and protein content and is thus mostly used as feed for animals (Xu and Hanna 2011). Recently, some studies have reported that hazelnut meal from Turkish cultivars can be used for feeding rainbow trout fish (Dogan and Erdem 2010) and European Seabass (Emre, Sevgili, and Sanli 2008) as a substitute for fishmeal and soybean meal. Other studies have reported the use of hazelnut meal in the feed of broiler chickens. The hazelnut meal protein extracts have been employed for developing transparent water-soluble edible films. The solubility and gelation properties of its protein extracts have been enhanced by acetone washing and/or heat treatment (Aydemir et al. 2014). Sometimes, the tree leaves, green leafy covers of nuts are composted and used as organic manures in agriculture and as compost for mushroom cultivation. Hazelnut leaves also have medicinal value (Ramalhosa et al. 2011). Studies have demonstrated that methanolic extracts from hazelnut leaves and stem significantly lowered the viability of some human cancer cell lines. So these can be used in pharmacotherapy of cervical cancer and hepatocarcinoma and to a lesser extent breast cancer. In folk medicine, infusion of leaves is used in treating piles, varicose veins, phlebitis, and edema of the lower limbs. In addition, other products such as bioethanol from hazelnut oil and hazelnut cake, charcoal from hazelnut branches can also be obtained by using different techniques. Hazelnut husk has an energy value of about 4.226 Kcal. Therefore, hazelnut can also be used in the production of electricity and hot water.

## 29.7 Conclusion

Hazelnut is an important tree nut grown and consumed in Europe, Asia, and America. Turkey is the leading producer of hazelnut in the world. The nut is roughly spherical to oval shaped with edible kernel inside the shell. The hazelnut kernel has a good nutritive value and is a good source of proteins, lipids, and different phytochemicals which have health-promoting properties. The nuts are consumed in different ways including roasting. The roasting brings many physicochemical changes in the kernel. The kernels possess good antioxidant activity which is due to the presence of phenolic compounds. The nuts are reported to have many health benefits and have shown beneficial effects in cardiovascular diseases, Alzheimer's disease, polycystic ovarian syndrome, and cancer.

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