Saghir Ahmad
Nasser Abdulatif Al-Shabib *Editors*

Functional Food Products and Sustainable Health

Springer

Functional Food Products and Sustainable Health

Saghir Ahmad • Nasser Abdulatif Al-Shabib
Editors

Functional Food Products and Sustainable Health

Springer

Editors
Saghir Ahmad
Department of Post Harvest Engineering and Technology
Aligarh Muslim University
Aligarh, India

Nasser Abdulatif Al-Shabib
Food Science & Nutrition Department
King Saud University
Riyadh, Saudi Arabia

ISBN 978-981-15-4715-7 ISBN 978-981-15-4716-4 (eBook)
https://doi.org/10.1007/978-981-15-4716-4

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

Natural and processed foods carry a number of ingredients, both major and minor. The functionality in the food may be brought by incorporating certain functional ingredients which provide health benefit and improvement in nutritional and sensory characteristics. It ensures that the food so prepared has good quality characteristics. It is safe, healthy, stable, and acceptable to the masses. Nowadays, consumers have become much conscious about the food safety and health beneficial effects. A variety of food can be produced by modifying flavor, aroma, color, texture, incorporating antioxidants, dietary fibers, and other food additives which support the quality, health benefit, and shelf life of the processed food. To incorporate the above values, it has been realized and the idea is being propagated in the form of a book that will fulfill the demands of the people. There is much discussion about the adequate diet for the world's increasing population, and efforts have already been made to fulfill the scarcity of food. The problem related to food quantity has almost been solved, but now it is the time of food quality in relation to the health issues of humans. The common health problems prevailing in the society are malnutrition, cardiovascular diseases, type-2 diabetes, and several other types of noncommunicable diseases such as cancer. The food we consume should be balanced in all manner that it should provide required calories plus chemical energies, namely minerals, vitamins, enzymes, antioxidants, and pigments. There are some ingredients that provide functionality, which means food play additional roles as providing health benefits. There has been an increased demand of consumer for functional food and therefore international health organization and government agencies prompted to develop specific guidelines for production of such foods.

This book includes 15 chapters primarily focusing on functional foods from selected sources going through different unit operations, namely processing, preservation, and packaging of variety of products. Some chapters provide insights about bioactive ingredients in processed food, while other chapters discuss the impact of natural antioxidants on human health and probiotic bacteria used in food.

Chapter 1 emphasizes on the importance of the role of bioactive ingredients in processed food as the bioactive ingredients help in sustaining the human body. Chapter 2 describes about the importance of natural antioxidants on human health. Natural antioxidants have been identified as substitute of synthetic antioxidants, and they do not carry any carcinogenic effect to the human when added in processed food. Chapter 3 describes the use of probiotic bacteria in processed food. The probiotic bacteria are the group of bacteria, namely lactic acid bacteria, to be incorporated in the food system which would be consumed by human being. When such bacteria are transferred into human digestive tract, they provide a system which conserves the digestion by preventing the effect of any harmful bacteria. Chapter 4 discusses the nutritional modification in meat food for protection of human health. Red meat has some saturated fatty acids which have adverse effect on human body. The level of animal fat is brought down by substitution of fat mimics system, which helps to prevent cardiovascular diseases in human. Fifth chapter advocates about the processing of by-products of food industry to make valuable dietary fiber. Chapter 6 describes the encapsulation of active ingredients in functional food. Encapsulation is modern technology which provides feasible consumption and their specific release in human digestive system. Chapter 7 provides information of cereals as functional ingredients in meat and meat products. Chapter 8 provides the information of dietary fiber and its role to prevent diseases in human when taken along with food diet. The dietary fiber acts as a roughage which is not digested by human digestive system, but it provides bulk to prevent constipation in human. Chapter 9 describes the role of food antioxidants in food preservation. Food products with plenty of fat are prone to be oxidized and spoiled due to rancid flavor. The antioxidants are incorporated in many commercial food products to protect them from oxidation. Chapter 10 throws light on dietary fiber as a functional food. Fiber though not giving any calories and also not digestible, they function in promoting the movement of material through digestive system. Chapter 11 describes the joint action of lipids and hydrocolloids in shaping the functional and nutritional aspect of processed food. In Chap. 12, the technology and prospect of fruit and vegetable based functional foods is discussed. Chapter 13 describes the importance of by-products of fruits and vegetables for development of functional food. Chapter 14 describes the application of lactic acid bacteria in fermented food and its therapeutic importance. The lactic acid bacteria have evolved as most promising bacteria carrying beneficial health effect on human being. Chapter 15 focuses on health and beneficial effects of flavonoids and its potential use in food system. Flavonoids are highly bioactive ingredients bearing antioxidants and color finishing properties.

We extend our sincere thanks to all our well-qualified and internationally renowned contributors for providing the relevant, reliable, and cutting-edge scientific information/technology to make this book a reality with great pleasure. All chapters are well illustrated with tables and figures properly placed and enriched with up-to-date information. We are very grateful to Springer Nature for the excellent assistance in producing this book. We sincerely thank the members of our family for their help and lament the disappointment and suffering that they endured when this book was planned.

Aligarh, Uttar Pradesh, India — Saghir Ahmad
Riyadh, Saudi Arabia — Nasser Abdulatif Al-Shabib

Contents

Editors and Contributors

About the Editors

Saghir Ahmad is a Professor and Chairman of the Department of Post Harvest Engineering and Technology, under the Faculty of Agricultural Sciences, Aligarh Muslim University (Aligarh), India. He is a respected scientist in the field of food technology, particularly meat processing and preservation. He holds B.Tech and M. Tech degrees in Food Technology from the prestigious Harcourt Butler Technical University, Kanpur (India), and in 2005 he completed his Ph.D. at the Department of Post Harvest Engineering and Technology, A.M.U. He has 35 years of experience, including 12 years in industry and 23 years in teaching and research. He completed two govt. (ICAR)-funded projects between 1999 and 2008, and was a team leader in All India Coordinated Research Project (AICRP) between 2007 and 2015. He is a member of several scientific societies, including the Indian Science Congress and the Association of Food Scientist and Technology (AFST), Mysore. He has published 53 research papers in leading national and international journals, and has participated in more than 20 conferences, presented 40 papers, and published two books. He contributed six chapters to and was a coeditor of the book "Food Processing: Strategies for Quality Assessment," published by Springer Science Business Media in 2014.

Nasser Abdulatif Al-Shabib is a well-known food scientist and an Associate Professor at the Department of Food Science and Nutrition, Food and Agricultural Sciences College, King Saud University (KSU), K.S.A. His research focuses on food safety. He completed his Ph.D. at Leeds University/Food Science and Nutrition Department, United Kingdom, in 2012, and he holds bachelor's and master's degrees in Food Science at Basrah University and the Food Science and Nutrition Department at KSU, respectively. He has worked in various capacities. He joined King Saud University as a Scientific Equipment Specialist at the Food and Nutrition Department in 1995, and was promoted to Assistant Professor of Food Safety at the same department in 2013, and to Associate Professor of Food Safety at the Department of Food and Nutrition, Food Sciences and Agriculture College, in 2018. He is involved in courses on food safety, including GAP, GMP, HACCP, HARPCs, and food allergy. He is a member of several scientific societies, and has participated in five international and national conferences. He has published 20 research papers on food science and food safety in leading national and international journals.

Contributors

Faizan Ahmad Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Iqbal Ahmad Faculty of Agricultural Sciences, Department of Agricultural Microbiology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Saghir Ahmad Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Thamer A. Albalawi College of Biology, Prince Sattam bin Andulaziz University, Alkharj, Saudi Arabia

Farhana Mehraj Allai Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Nasser Abdulatif Al-Shabib Faculty of Food and Agricultural Sciences, Department of Food Science and Nutrition, King Saud University, Riyadh, Saudi Arabia

Abdullah Alyousef Department of Clinical Laboratory Sciences, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia

Mohammed Arshad Department of Clinical Laboratory Sciences, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia

Shayeeb Ahmad Bhat Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Ishfaq Hamid Dar Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Abdul Haque Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Iftekhar Hassan Department of Zoology, College of Science, King Saud University, Riyadh, Saudi Arabia

Fohad Mabood Husain Faculty of Food and Agricultural Sciences, Department of Food Science and Nutrition, King Saud University, Riyadh, Saudi Arabia

Sattar Husain Faculty of Engineering and Technology, Department of Chemical Engineering, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Kausar Jahan Department of Bioengineering, Integral University, Lucknow, Uttar Pradesh, India

Sweta Joshi Department of Food Technology, School of Interdisciplinary Science and Technology, Jamia Hamdard, New Delhi, India

Altaf Khan Department of Pharmacology and Toxicology, Central Laboratory, College of Pharmacy, King Saud University, Riyadh, Saudi Arabia

Irfan Khan Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Abdul Malik Faculty of Agricultural Sciences, Department of Agricultural Microbiology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Arshied Manzoor Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Farhana Masood Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Ovais Shafiq Qadri Department of Biotechnology, Thapar Institute of Engineering and Technology, Patiala, Punjab, India

Rayees-ul-Islam Department of Bioengineering, Integral University, Lucknow, Uttar Pradesh, India

Nazia Tabassum Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Tawheeda Yasin Institute of Home Science, University of Kashmir, Srinagar, Jammu & Kashmir, India

Kaiser Younis Department of Bioengineering, Integral University, Lucknow, Uttar Pradesh, India

Insha Zahoor Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Sadaf Zaidi Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

1 Bioactive Ingredients in Processed Foods

Sattar Husain and Saghir Ahmad

Abstract

India produces some food items like fruits and vegetables on a massive scale. It ranks second in the world. Basic needs of the body like carbohydrates, proteins, minerals, and vitamins are supplied by horticultural crops and legumes. Fruits and vegetables have some extra benefits of providing the source of some compound which are biologically active and promote the metabolism in the humans. The by-products of the fruits and vegetables are important in providing safety to human health and also giving additional antioxidants to the body. In many aspects of human life, plenty of fruits and vegetables are consumed and hence they evolve a lot of solid waste on Earth's surface. There is requirement of managing the waste evolved from fruit and vegetable products and provides solution to the environmental problem arising from the waste. It will be wise enough to recover these bioactive ingredients like phenolic compounds and antioxidants and their utilization in industries such as food, pharmaceuticals, and other products. Bio-active compounds formed from polyunsaturated fatty acids (PUFA) provide tremendous health benefits to humans like controlling diabetes, cancer, and cardiovascular diseases. Toxins are bound by some bioactive compounds to avoid carcinogenesis. The quality awareness of foods and nutritional value is increasing worldwide among the consumers. These consumers are looking for new, energetic, and healthy foods for weight control, cardiovascular diseases, osteoporosis, inflammation, type-2 diabetes, digestive health, immune system and antiaging, and other chronic degenerative diseases. This chapter aims to

S. Husain (✉)
Department of Chemical Engineering, Zakir Husain College of Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Ahmad
Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_1

discuss the need for bioactive food ingredients to be delivered and released at their target site for its optimal health benefits.

Keywords

Bioactive ingredients · Fruits and vegetables · Agro waste · Antioxidants · Human health

1.1 Introduction

The food industries in India have passed through phases of many changes in production, consumption, marketing, quality awareness, and health standards in the last few decades. This is a joint endeavor of Indian Govt., industries, research scientists, engineers, and food technologists. The govt. has given incentives and has encouraged promoting both the aspects of industrial sector, i.e. indigenous production and exporting as well. To increase the production, there is significant contribution of food engineers and technologist, across the world. The quality of food products has improved many folds. The retail marketing has gone to super market via malls and departmental stores. The food quality has improved through enhanced and innovative technologies. Quality of food also effects the human health by providing nutritious compounds in the diet and also by preventing many diseases by incorporation of some functional ingredients in processed foods. The bioactive ingredient is defined as a compound that has an effect on a living organism, tissue, or cell. The nutrients are essential for the sustainability of a body, the bioactive ingredients/compounds are not essential since the body can function properly without them or because nutrients fulfil the same function. The bioactive compounds can have an influence on health. Bioactive food components are usually found in multiple forms such as glycosylated, esterified, thiolated, or hydroxylated. These are found in plant foods (whole grains, fruits and vegetables, etc.). However, probiotics are bioactive peptides which are most commonly found in animal products. Health is defined by World Health Organization as state of complete physical, mental, and social well-being and not merely the absence of diseases or infirmity. Food processing is the procedure our food goes through before reaching our dining tables. The harvested crops and slaughtered animals are also processed by a set of techniques and methods through which they are transformed into attractive and marketable food products for humans (or other animals). Some of the techniques which can be applied for such processing can be named such as heat treatment, biochemical treatment, wet or dry treatment, size reduction, packaging, and other types. These methods lead to better food preservation. In general, a food material is processed, stored, and handled during every step of its trip to our dining tables. But this can make it vulnerable to viral, bacterial, and also fungal contamination. The foodborne diseases and viruses such as *E. coli* and Hepatitis A can be deadly. According to a study by Paul Mead in the national Centre for Biotechnology Information (NCBI) and the Centre for Disease Control and Prevention (CDCP), more than 5000 deaths due to foodborne diseases occur in the US alone. The fact is the food we purchase from the supermarkets travels a long way from the farm or factory where it is produced.

The date fruits are important economic commodity that are regularly consumed by middle east populations for health benefits and pleasant taste. They are consumed as fresh or processed in many products such as date jam, date butter, date bars, date relish, date pickles, date oil, and date coffee (Al-Mamary et al. 2014; Benmeddour et al. 2013). Date paste is widely used as filling for bakery products and date syrup is well known natural sweetener in dairy products. Date fruits have high potential to be used as functional food ingredient due to their properties including the high content of fiber, high content of bioactive compounds, broad range of applications. Date fruits have many health benefits because of carbohydrates, minerals, proteins, lipids, moisture, and phenolic compounds. Date fruit's phytochemicals are reported to have biological activities such as antioxidant, antimutagenic, anticarcinogenic, antimicrobial, and anti-inflammatory.

In recent years, there is a global trend toward the use of phytochemicals from natural resources such as vegetables, fruits, oilseeds, and herbs, as antioxidants and functional ingredients. The extraction of bioactive compounds present in pomegranate, mango, grapes, stress peels, pine apple waste, tomato, potato, sweet potato, and beet root will enhance the food quality during processing of wastes which are of economic importance. Table 1.1 indicates various antioxidants and their food sources. Out of these bioactive compounds most of them have good potential of preventing several noncommunicable diseases and provide health benefits. Wastes such as stress fruit skins, potato peel, pine apple residues, tomato skin, and other fruit and vegetable residues are generated in large quantities in big cities. Agro waste has become one of the main sources of pollution for municipal solid wastes (MSW) which pose environmental issues. There are two techniques to dispose MSW, i.e., landfill and incineration. Inappropriate management of landfill will result in emissions of methane and carbon dioxide. Incineration involves development and release of pollutants and secondary wastes such as dioxins, furans, acid gasses as well as particulates, which pose severe environmental and health risks. There is a critical need to seek out resource and value-added use of these wastes. One of the most advantageous approaches is to recover the bioactive constituents, mainly the phenolic compounds, utilization of it in the food, pharmaceutical as well as cosmetics industry. Constituents and their utilization in the production of nutraceutical will act not only as value addition but also help in dropping environmental pollution. Antioxidants from fruit wastes have been suggested to be useful in the food, cosmetic, and pharmaceutical industries which can be used as substitute of synthetic antioxidants. Synthetic antioxidants such as butylated hydroxy toluene and butylated hydroxy anisole used as food additives not preferred because of negative effects on human health. Fruits and vegetables are the prime sources of natural antioxidants. The plant extracts also show strong antioxidant capacity both in vitro and in vivo. The extracts can be considered a good source of natural antioxidants and antimicrobials. Natural bioactive compounds have been found to interfere with and prevent all kinds of cancers. The flavonoids have shown to work as antitumor agents involving a free radical quenching mechanism. They also play significant multiple

Table 1.1 Antioxidants: health benefits and food sources

Antioxidants	Health benefits	Natural sources
Rutin, apigenin, quercetin, hesperidin (flavonoids)	Maintains heart and brain functioning, improves immune system and prevents bolster cellular oxidation	Apples, apricots, blueberries, pears, bolster cellular antioxidant raspberries, strawberries. Black beans, cabbage, brain onions, parsley pinto beans, black tea. Celery, apigenin, citrus fruits, green tea, luteolin, olives, oregano, grape, purple grape juice, soybeans and soy products, green vegetables, and wheat (whole)
Isothiocyanates	Decreases the chances of cancer (prostate and breast), deactivates and speeds up the removal of cancer-causing agents, and plays vital role in detoxification of undesirable compounds	Vegetables (broccoli, cauliflower, kale, turnips, collards, Brussels sprouts, cabbage, Chinese cabbage, bok choy, radish, and watercress)
α, β, and γ-carotenes, β-cryptoxanthin, lycopene, zeaxanthin, lutein, and astaxanthin	Prevents bolsters cellular oxidation, free radical scavenging acts as anticarcinogen, antiaging agents and improves immune system, thereby, combating the fatal diseases risk	Carrots, sweet potatoes, spinach, kale, and greens tomatoes (deeply pigmented fruits and vegetables)
Resveratrol	Helps in declining LDL, cholesterol level, along with protecting lining in blood vessels of heart, thereby reducing blood clots	Wine (red), grapes (red and purple) and juice, peanuts, berries such as blueberries and cranberries
Tannins	Acts as antiviral, antibacterial, and antiparasitic and declines the cancer risk	Pomegranates, persimmons, nuts, lentils, wine (red and white), tea (green)

roles including mutagenic cell damage, carcinogenic due to their acceleration of different aging factors (Altemimi et al. 2017). Different types of waste obtained from fruits and vegetables containing phenolic compounds are given in Table 1.2.

Fruit and vegetable wastes have always been a source of raw materials for several industries, viz. pharmaceutical, cosmetic, nutraceutical, and value-added food products enriched with antioxidants. On one hand, these wastes and residues are utilized successfully, and on the other hand they cooperate in saving environmental pollution. Bioactive constituents and some important minerals are also extracted from the residues and wastes of fruit and vegetable industries. A group of synthetic antioxidants such as butylated hydroxyanisole, butylated hydroxytoluene, and tributylated hydroxyquinone earlier were used as food additives to prevent oxidation in food rich in fat. Now, the antioxidants derived from natural sources such as fruit

Table 1.2 Bioactive compounds from different fruit and vegetable wastes

Fruit/ vegetable	Description of waste	Bioactive compounds
Beetroot, mango	Peel	Flavonol glycosides, ferulic acid, L-tryptophan, *p*-coumaric acid
Grapes	Seeds, skin	Catechins, anthocyanins, stibenes, flavonol
Citrus fruit	Peel and solid residues	Eriocitrin, hesperidin
Onion	Skin	Quercetin 3, 40-*O*-diglucoside
Potato, tomato	Peel	Chlorogenic, galic acids, lycopene
Pomegranate	Seeds, peel	Anthocyanins, ellagic acid

and vegetable wastes have significant role in preventing the risk and carcinogenic effect caused by the synthetic antioxidants. They are also widely used in nutraceutical food preparation. A large number of compounds acting as antioxidants are found in fruit and vegetable wastes giving enormous benefits, viz. phenolic compounds and flavonoids which help to impart anticarcinogenic effect to human body. They also prevent formation of tumor in human body and hence acting as antitumor agents. Some fruits have antioxidants like phenols in their flesh and peel part. Pomegranate peel and pulp has lowest phenolic compounds as antioxidants, while the fruit part has highest value of phenols. The carrot available in dark color has highest antioxidants as phenolic compound, while orange color carrot has lowest antioxidants (Pande and Akoh 2009). Antioxidant activity and their presence reduce the development of certain kinds of cancer (Joana Gil-Chávez et al. 2013).

A strong relation between regular consumption of phytochemical products like phytosterols, carotenoids, and polyphenol and lifestyle disease prevention like obesity, cancer, cardiovascular complications, and diabetes has been shown by research activities (Gresele et al. 2011). The intake of purified lycopene led to minimal protection from prostate cancer in rats, while tomatoes reduced the risk by 26% more successfully (Boileau et al., 2003). Owing to the beneficial and synergistic influence of nutrients and phytochemicals in fruits and vegetables, the effective antioxidant and anticancer properties could be expected (Liu 2003). High intake of tomatoes and tomato products was associated with lower carcinogenesis, especially prostate cancer because of the lycopene presence which impart red color to tomatoes (Giovannucci 2002).

Bioactive materials have demonstrated activation of the phycogenetic activity of macrophages and the formation of many forms of immune cells, thereby increasing the protection against infection, e.g., broccoli, garlic, onions, vegetable oils, and almonds. Many foods are good sources of antioxidants. Researchers have still not established precisely how all the various systems inside our bodies function together to protect us against free radical harm. The protection provided by all the antioxidants functioning together cannot be provided by any one antioxidant. Vitamins C and E act as antioxidants. Some minerals like manganese and selenium

Table 1.3 Bioactive compounds: Methods of extraction from agro processing waste

Bioactive compounds	Method of extraction
Lipid/fat	Soxhlet extraction
Oil and bioactive compounds	Hydrodistillation method
Phenolic compounds	Liquid–liquid extraction
Phytochemicals	Solid phase extraction method
Volatile compounds	Various supercritical fluid extraction (SFE) methods
Agro industrial by-products phytochemicals	Liquid extraction under pressure
Polyphenols	Pulsed electric field (PEF) method
Oil and bounded phytochemicals	Extraction using enzymes
Polyphenols	Microwave-assisted extraction (MAE)
Carotenoids, polyphenolic compounds	Ultrasound-assisted extraction (UAE)

also act as antioxidants, and some plant compounds like beta carotene and lycopene act as antioxidants.

The food industry establishes critical ties and synergies between agriculture and industry. India has the highest production, consumption, export, and growth opportunities in the food processing industry. The government put it high on the agenda with a range of fiscal subsidies and incentives to facilitate marketing and add value to agricultural products, to reduce pre-/postharvest waste, create jobs and increase exports. This includes a wide variety of products, fruits and vegetables, poultry and meat, alcoholic beverages, milk and milk products, fisheries, plantation, grain processing, and other consumer product categories such as confectionary, soya-based products, chocolates and cocoa products, mineral water, and high protein foods. India produces annually 90 MT of milk (highest in the world); 150 MT of fruits and vegetables (second largest); 485 Million Livestock (largest); 204 MT of food grains (third largest), as a result, the food processing industry has become an attractive destination for investors worldwide. India produces 90 million metric tons of milk (top in the world) each year; 150 thousand metric tons of fruits and vegetables (second largest); 485 million livestocks; 204 thousand metric tons of food grains (third largest), therefore the food processing industry has become a worldwide attractive investor's destination. Different methods of processing agro waste for extraction of bioactive compounds are shown in Table 1.3.

In the food processing market, India has many advantages. India is one of the leading food producers worldwide, and in addition, India has a huge pool of science and research talents with a largely unused domestic market, a wide variety of agroclimate conditions, and a large raw material base suitable for food processing companies. Rapid urbanization, increased literacy, changing habits, and rising per capita income have contributed to quick growth and great opportunities in the food and beverage industries.

Just about 2% of the fruits and vegetables are processed, and the figure is 15% for milk, 6% for poultry, 26% for marine, and 20% for buffalo meat as compared to

Table 1.4 Bioactive food components: common sources and the functional roles

Biologically active component	Natural Source	Functional role
Tocotrienols along with tocopherols	Seeds, nuts, oil of vegetables	Prevents oxidation and acts as immunomodulator
Isothiocyanates glucosinolates, diallyl sulfides	Vegetables such as onions, cauliflower, broccoli, Brussels sprouts, and garlic	Prevents microbial action and acts as anticarcinogen, immunomodulator detoxifying agent for enzyme systems
Polyphenols, isoflavonoids	Fruits and vegetables (fresh) grapes, wine(red), tea	Prevents lipid oxidation, and acts as anticancer, immunomodulatory and antiosteoporotic
Genistein, daidzein (phytoestrogens)	Legumes, soybean along with soy-based products, flaxseed, cabbage	Prevents osteoporosis, and acts as antiestrogen, antiproliferative
Phytosterols	Nuts along with vegetable oils	Reduces lipid levels
Fiber (dietary)	Fruit with skin (fresh), grains (whole), and oats	Reduces lipid levels
Lutein	Leafy vegetables (green)	Combats macular degeneration
Carotenoids	Carrots, leafy vegetables (green), fruits (oranges, papaya, red palm oil)	Combats oxidation and acts as immunomodulator
Lycopene	Ripe tomatoes	Acts as anticarcinogen and antiproliferative

60–70% of total food production in developed countries. Milk and milk products account for almost 17% of total food consumption in countries. The main players in the food processing sector in India and abroad include ITC limited, Parley Products, Agrotech foods, Amul, Cadbury, and Nestle. With a changing population lifestyle, increasing income of middle class, fruit vegetables and milk surpluses, Northern India quickly emerges as a hub of the food manufacturing industry. Currently, 20–25% of fruits, vegetables, and milk are being processed in the north region, compared with approximately 10% in the country. Towns like Jalandhar, Ludhiana, Karnal, Ambala, and Solan are established as centers of food processing sector. The market size in India is expected to grow from $155 bn in 2005 to $344 bn in 2025 at an annual growth rate of 4.1%. Table 1.4 shows the bioactive ingredients, their source, and functional properties.

Several types of bioactive food components are generally found in the form such as esterified, glycosylated, hydroxylated, and thiolated. These are found in plant foods (whole grains, fruits and vegetables, etc.). However, probiotics are bioactive peptides most commonly found in animal products. Health is defined by WHO as state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.

Food processing is the procedure where food goes through formulations and different unit operations before reaching our dining tables. The harvested crops and slaughtered animals are often processed through a series of approaches and techniques through which they have been converted into desirable food products for humans or other animals that are marketable. Some of the methods that can be used for processing are biochemical treatment, heat treatment, wet or dry treatment, reduction in bulk, packaging, etc. These methods lead to a better food preservation.

In general, a food material is processed, handled, packaged, and stored and preserved till it is served to the consumer, but this may make it susceptible to bacterial, viral, and also fungal contamination. The foodborne diseases and viruses like *E. coli* and hepatitis A can be lethal. More than 5000 deaths due to foodborne diseases have taken place in America alone, as per Paul Meade's report in the National Center on Biotechnology Knowledge (NCBI) and the Centre for Disease Prevention (CDCP). The fact is that the food we purchase from supermarkets travels a long way from the farm to the factory and till it reaches to the fork, where it was produced, processed, marketed, and consumed. It indicates the importance of food, its processing, wastes utilization, and safety aspects to the human being. The safety plans include the HACCP procedures during production, processing, packaging, marketing, and distribution.

1.2 Conclusion

Nutritional quality in food is of great importance, which can be glorified in the form of major and minor components along with some medicinal characteristics to provide effects on human health. In western world functional foods/nutraceutical are nicely designed. It takes due consideration of great application, marketing potential, and making them capable of preventing from the diseases. The potential bio-resource for a section of bioactive components emanating from industries is hazardous to the environment. However, the different technologies can result into extraction of bioactive components which can be incorporated in processed food and make nutraceutical and dietary supplements. There are some hazardous organic solvents used in the extraction process which are not environment friendly. However, some solvents which come into category of green and safe solvents such as carbon dioxide, ethanol, and water are the prime objective of this chapter. The steps should be taken to plan more rational use of natural resources of food wastes. The commercial application of such residues will require a detailed economic analysis of these extraction techniques. Thus, a perfect utilization of food industry wastes (e.g. the dairy waste, in the form of water has high BOD 4500 mg/L and having high COD 12000 mg/L) will offer the better economic return, generate the job opportunities and will also ensure the prevention of environmental pollution to good extent.

References

Al-Mamary M, Al-Habori M, Al-Zubairi AS (2014) The in vitro antioxidant activity of different types of palm dates (*Phoenix dactylifera*) syrups. Arab J Chem 7(6):964–971

Altemimi A, Lakhssassi N, Baharlouei A, Watson DG, Lightfoot DA (2017) Phytochemicals: extraction, isolation, and identification of bioactive compounds from plant extracts. Plan Theory 6(4):42

Benmeddour Z, Mehinagic E, Le Meurlay D, Louaileche H (2013) Phenolic composition and antioxidant capacities of ten Algerian date (*Phoenix dactylifera* L.) cultivars: a comparative study. J Funct Foods 5(1):346–354

Boileau TWM, Liao Z, Kim S, Lemeshow S, Erdman JW Jr, Clinton SK (2003) Prostate carcinogenesis in N-methyl-N-nitrosourea (NMU)—testosterone-treated rats fed tomato powder, lycopene, or energy-restricted diets. J Natl Cancer Inst 95(21):1578–1586

Giovannucci E (2002) A review of epidemiologic studies of tomatoes, lycopene, and prostate cancer. Exp Biol Med 227(10):852–859

Gresele P, Cerletti C, Guglielmini G, Pignatelli P, de Gaetano G, Violi F (2011) Effects of resveratrol and other wine polyphenols on vascular function: an update. J Nutr Biochem 22 (3):201–211

Joana Gil-Chávez G, Villa JA, Fernando Ayala-Zavala J, Basilio Heredia J, Sepulveda D, Yahia EM, González-Aguilar GA (2013) Technologies for extraction and production of bioactive compounds to be used as nutraceuticals and food ingredients: an overview. Compr Rev Food Sci Food Saf 12(1):5–23

Liu RH (2003) Health benefits of fruit and vegetables are from additive and synergistic combinations of phytochemicals. Am J Clin Nutr 78(3):517S–520S

Pande G, Akoh CC (2009) Antioxidant capacity and lipid characterization of six Georgia-grown pomegranate cultivars. J Agric Food Chem 57(20):9427–9436

The Impact of Natural Antioxidants on Human Health

2

Irfan Khan and Saghir Ahmad

Abstract

Natural antioxidants are the molecules that present in natural sources which resist or inhibit any kind of oxidation process in plant cell and animal cell as well. Generally, oxidative reactions continuously take place in the human body sometime with very slow rate and higher rate relative to concentration of free radicals in the cell. The free radicals may cause minor or major oxidative damages in the human body, and in most extreme cases it may cause irregularities in the cell growth cycle that accelerates the rate of cell growth, leading to a number of disorders, viz. malignancy and malfunction in the apoptosis mechanism. To get rid of the above problems, people should continuously consume the food sources that fulfil the daily requirement of antioxidants. The natural antioxidants are found in a variety of foods, including fruits, vegetables and cereals. Although, oxidation is an important phenomenon in human body that helps in the lysis of harmful cells. There is a variety of natural antioxidants, such as glutathione, vitamin C, vitamin A and vitamin E as well as enzymes such as catalase, superoxide dismutase and various peroxides. At present, the consumers have been shifted their priority towards food safety over food quality. This awareness of the consumers towards food safety has now been endorsed to industries to substitute/replace the chemical antioxidants with natural antioxidants in processed food products. In the ancient period, in traditional herbal medicines, dietary foods were the main sources of natural antioxidant that protected them from the damage caused by free radicals. Natural antioxidants are widely used in dietary supplements and have been investigated for the prevention of number of non-communicable diseases such as cancer, coronary heart disease, and altitude sickness. These may be a sustainable substitute for chemical preservatives in a

I. Khan (✉) · S. Ahmad
Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_2

variety of functional food products to reduce chemical hazards on human health. This chapter covers the processing of food to incorporate the natural antioxidants in the diet that will be beneficial for human health.

Keywords

Natural antioxidants · Food · Health

2.1 Introduction and Brief Touch of Nature

Allah, the most exalted and most merciful, has created the universe in extraordinary beautiful way. The plants, animals, organisms in between, all the creations have beautiful systems to move their life in the environmental condition provided by the supreme power. The most typical instance how beautifully Allah has created the universe is the proportion of atmospheric gases in strictly in a certain ratio, i.e. 20.95% oxygen, 78.09% nitrogen, 0.93% argon, 0.04% carbon dioxide and small amounts of other gases. The presence of nitrogen gas in highest proportion may be to provide inertness in the atmosphere to check the sparks and other hazards that may turn into massive blast. Physically and within the range of human neurons, it is absolutely impossible to imagine the existence of earth without the nitrogen gas. This ability of nitrogen comes with half-filled p-orbital ($N_7 = 1S^2, 2S^2, 2P^3$) which is comparatively more stable than the fulfilled and partially filled p-orbital. So, this way one can understand the supremacy of Allah who kept nitrogen in larger proportion to provide the sustainability of universe. There are hundred millions of examples that tell about the excellence of supreme power. Though, it is quite impossible to discuss all the things in a single chapter. The antioxidants have the similar function in the human body as the role of nitrogen in the atmospheric gases. It is very difficult to cover all the aspects of natural antioxidants in this chapter. However, an effort has been made to summarize the importance of antioxidants present naturally in plant systems and their probable effects on the human health. Although, human body itself carry a number of antioxidants that provide the safety against number of metabolic disorders and problems leading to lethal diseases. In this chapter, the emphasis has been given only on the antioxidants from the plant sources that directly or indirectly help to strengthen the innate immunity of the human body. It can be concluded that antioxidants provide the first line of defence to the human body. There are numerous molecules in the living cells of human body which are prone to oxidation. So, to inhibit these molecules to oxidation by the oxygen, a variety of antioxidants are present in the human body. The oxygen (O_2) molecule has the ability to cause oxidation of other molecules by accepting the electrons from the other species.

2.2 Understanding the Chemistry of Oxidation

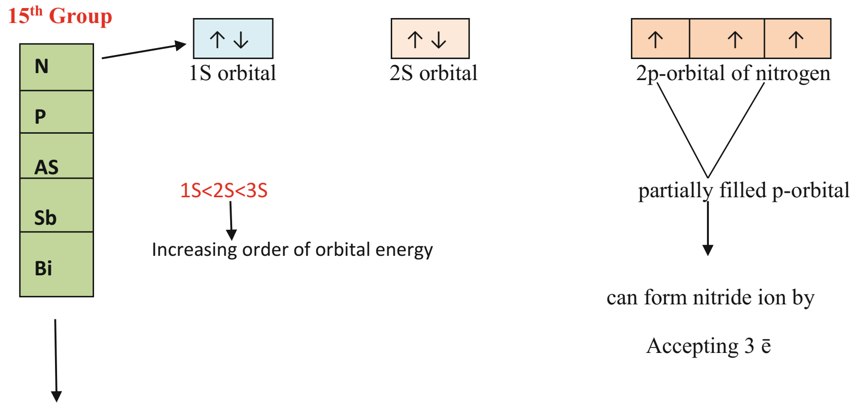
To understand the effect of oxidation on the molecules, it is mandatory to discuss the oxidation phenomenon. As per the most accepted definition of oxidation, the oxidation is the process involving the transfer of electron from the oxidizing agent to the molecule which is being oxidized (Shammas et al. 2005). So, in the oxidation process, the main concern is the transfer of electron which decides the increase or decrease in the oxidation number of target molecules. As per the electronic definition, the increase in the oxidation number of a molecule is called oxidation, while the decrease in the oxidation number is called the reduction phenomenon. The oxidizing agents must have vacant orbital, electron withdrawing power and respective energy level of central atom to oxidize the other molecule and to be reduced itself. The ability to attract the shared pair of electrons from the target molecules is the chief feature of oxidizing agents. The ability of specific oxidizing agent depends upon the range of oxidation number of its central atom which is calculated with the help of the equation given below:

$$\begin{aligned}&\text{The range of oxidation number of central atom}\\&\quad = \text{Group number of central atom} - 8 \text{ to group number}\end{aligned}$$

The oxidizing behaviour can be understood by taking an example of oxidizing agent, for instance nitric acid, HNO_3, is the strong oxidizing agent. Let us apply the above rule to calculate the ability of nitric acid towards oxidation. In HNO_3 molecule, the central atom is the nitrogen atom and its oxidation state in the molecule is +5, while the range of oxidation number of nitrogen atom in the same molecule lies from −3 to +5. This indicates that the oxidation number of nitrogen atom cannot move beyond +5, i.e. the nitric acid cannot oxidize itself and hence cannot reduce to other species. However, the oxidation number of nitrogen atom can go down till −3 oxidation number. This indicates that the nitric acid can reduce itself from +5 to −3 oxidation state and can strongly oxidize to other species. This self-reducing property of nitrogen atom in nitric acid makes the acid a strong oxidizing agent. Similarly, hundreds of molecules are present in the nature that acts as oxidizing agents within the living system. Although, the reactive oxygen species produced normally as a by-products of oxygen metabolism. This reactive oxygen species plays several important physiological functions, viz. cell signalling in the human body. When these reactive oxygen species increases greatly as influenced by environmental stressors, viz., ultra violet radiations, ionizing radiations, heavy metals and variety of pollutants, it lead to oxidative stress and pose harmful effects on the human body (Pizzino et al. 2017).

To understand the concept of oxidation, it is important to discuss with suitable example. Let us discuss the distribution of electrons in the nitrogen atom as according to the Aufbau's principle. According to this principle, the electrons will be filled first in the orbitals of lowest energy levels before occupying higher energy levels.

In the nitrogen atom, the p3-orbital ($N_7 = 1S^2, 2S^2, 2P^3$) having three unpaired electrons provides the ability to join with other groups or molecules.



General configuration of all 15th group elements is ns^2np^3 in their outer shell where "n" representing the principle quantum number of the element. From the above discussion, it is clear that the ability of oxidation of any molecule depends upon the oxidation state of central atom of that molecule, i.e. the tendency of oxidation is directly proportional to the ability of an element to lose the electron. As going from down the group, the effective nuclear charge increases which reduces the electron donating ability of the elements.

2.3 Deleterious Effect of Oxidants on Human Health and Food System

It is amazing that, in certain cases, oxygen, which is an essential element of life, has extreme deleterious effects on the human body. The harmful effects of oxygen are due to the production of reactive oxygen species (Anbudhasan et al. 2014). The reactive oxygen species (ROS) and reactive nitrogen species (RNS), i.e. hydroxyl, superoxide and nitric oxide, can damage the nucleic acid, viz., DNA and RNA, and can also destroy the functionality of protein and lipids in the biological system (Xu et al. 2017). Several researchers also claimed the beneficial effects of reactive oxygen and nitrogen species (Valko et al. 2006). The reactive oxygen species act as secondary messenger within the cell that play an important role in maintaining the oncogenic phenotype of cancer cells (Valko et al. 2006). The reactive oxygen species are evidenced to show antitumourigenic activity by inducing the cell senescence and apoptosis. These oxidizing agents affect the human body and food system leading to number of lethal diseases and degraded food quality, respectively. By adding suitable antioxidants, the effort to produce free radicals in the food matrix has now increased below the cap of consumption (Hillmann 2010).

The formation of free radicals can be taken place by three ways listed below:

1. By homolytic fission of covalent bond of normal molecule

$$X - Y \rightarrow \underbrace{X^{\circ} + Y^{\circ}}$$

   Both *X* and *Y* free radicals carry unpaired electrons after the homolytic fission
2. By addition of single electron to a normal molecule

$$X + \overline{e} \rightarrow X^{-}$$

3. By loss of single electron from a normal molecule

$$X - Y \rightarrow X^{\circ} + Y^{-}$$

Today, people are relying on the low or reduced fat food products. Generally, animal fat in the food products is being replaced by a variety of natural and synthetic fat replacers based on carbohydrate, lipid, and protein. In case of replacement with vegetable oils rich in unsaturated fatty acids, a major problem is the susceptibility of unsaturated fatty acids towards oxidation. The food technologists are now adding antioxidants in the products to inhibit the oxidation of fatty acids and improving the quality and shelf life of food products. The natural antioxidants, viz., ascorbic acid and α-tocopherol, is used to add in the processed meat products such as sausage, and salami. In human body, the balance between oxidants and antioxidants is sufficient to maintain the normal physiological function. Anyhow the increase or decrease in the concentration of antioxidants or oxidants can disrupt this balance.

This imbalance leads to the generation of free radicals which occurs continuously as a result of common metabolic process, and high concentration of these free radicals (oxidants) induce oxidative stress which causes serious implications in the cell biomolecules of body, viz. nucleic acid, lipids and proteins leading to impaired cell function and cell death in strict condition (Aslani and Ghobadi 2016; Phaniendra et al. 2015). The greater proportion of oxidants (free radicals) also affect the physiological functioning of various cell organs viz. liver, kidney, lungs and brain and result into a number of human diseases (Alkadi 2018). The oxidative stress is an initiator to release the cytokines and ultimately cell damage and responsible for diverse lung problems, viz. asthma, interstitial lung diseases and chronic obstructive pulmonary disease (Bowler and Crapo 2002). If not cured at right time, this multi-organ damage may lead to death of the individual. As the data suggest, the increasing death frequency is caused by failure of organs like liver failure, kidney failure and neurodegenerative disorders. The oxidants also deteriorate the food quality by oxidizing oils/fat of fat, food colour, food enzymes and flavour compounds present in food. The consumption of food having oxidized oil/fat leads to cell toxicity and may pose oxidative stress in the human body. It may result into a number of disease conditions. To counter the effect of oxidants in food, the food technologists are incorporating various natural and synthetic antioxidants and simultaneously utilizing a number of latest technologies to minimize the oxidation effects in food and to preserve the quality of the food and food products. Today, the people are moving towards the organic life style from the synthetic world. The threat has evolved with changing lifestyle, food habits and taking adulterated oils/fat, spices other food items, etc. The balance between oxidants and antioxidants in human body is important to get the healthy life. The imbalance in the oxidants and antioxidants leads to a number of problems in the human body, viz. carcinoma, atherosclerosis and increased frequency of cardiovascular diseases. The antioxidants play a crucial role in the detoxification of body by inhibiting or neutralizing the free radicals. The impact of oxidants is shown in Fig. 2.1.

2.4 Natural Antioxidants: The Boon of Nature

The growing interest in the area of food processing is the replacement of synthetic antioxidants with the natural antioxidants. This approach has fostered the research and development on plant sources and the searching of new potential antioxidants. The antioxidants are the molecules that neutralize the effects of oxidants in human body and in the food system. The antioxidants help cells to fight against oxidants and their harmful effects in human body as well as in food system.

It is claimed by the scientific community that significant amount of antioxidants supplied through food boosts the innate immunity and improved the defensive potential of cells. Antioxidants may be used for protecting the organoleptic and nutritional quality of the food. They provide immunity to the body against chronic and age-related diseases. Antioxidants protect human body from the deleterious effects of free radicals. Antioxidants generally found in natural sources like fruits and vegetables. The antioxidants can be natural and synthetic depending on its origin, i.e. natural and synthetic antioxidants. The synthetic antioxidants are toxic and increase the load on the human organs which may hamper the normal functioning of human organs. So, it is the need of today to replace the synthetic antioxidants with the natural ones to get the healthy and sustainable lifestyle. The use of synthetic antioxidants viz. butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) in processed food products is the concerning issue regarding their use for health consumption. The negative health impact of synthetic antioxidants endorse consumer to take natural antioxidants. In pursue of healthy and sustainable life style, the people should take natural antioxidants with their diet viz. vitamin E (α-tocopherol), vitamin C (L-ascorbic acid), coenzyme Q, β-carotene (vit-A) and variety of phenolic antioxidants that inhibit the free radical formation (Brewer 2011). The antioxidants from fruits and vegetables are mostly of phenolic in nature. Antioxidant minerals viz., iron, manganese, zinc, selenium and copper play crucial role as a cofactor of several antioxidant enzymes, absence of which may hamper the activity of their enzymatic scavenging activity (Sonia et al. 2016). Among the category of vitamins, vitamin C (L-ascorbic acid) and vitamin E (α-tocopherol) are

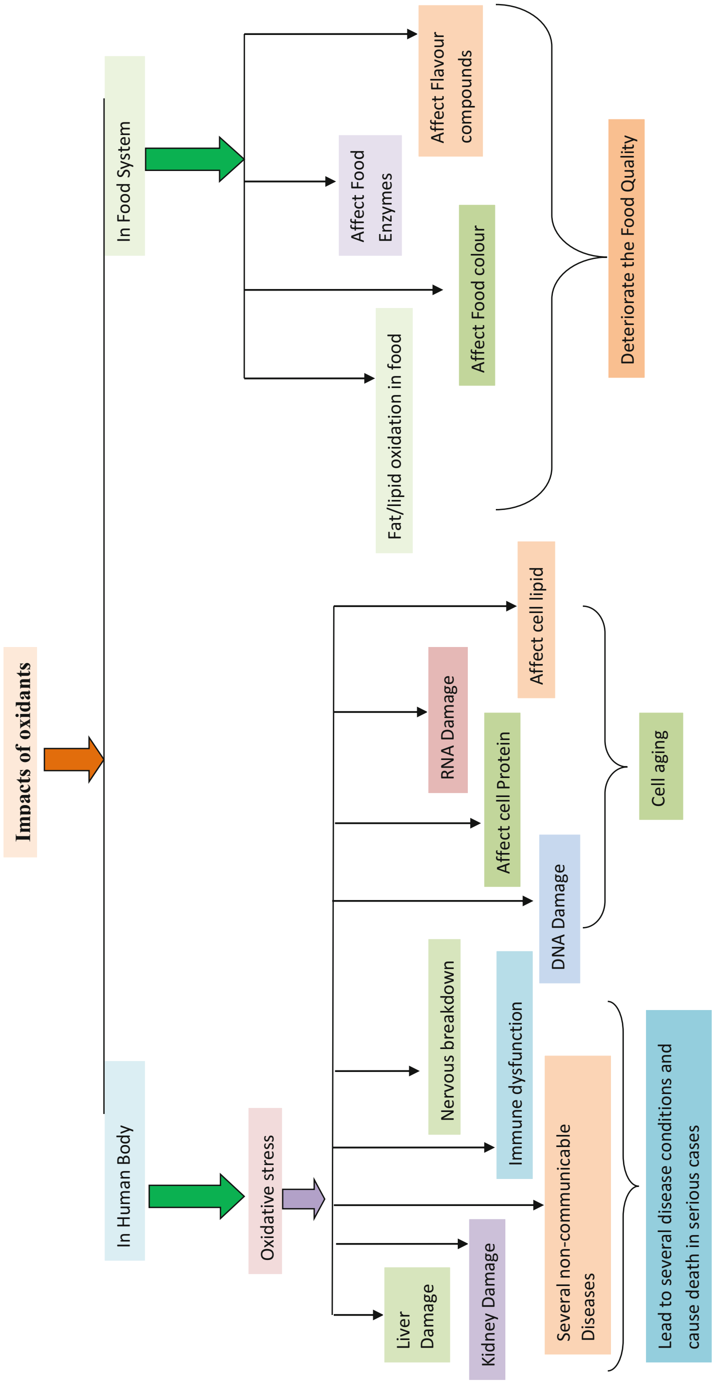


Fig. 2.1 Effects of oxidants on food system and human body (Source: Alkadi 2018; Aslani and Ghobadi 2016; Phaniendra et al. 2015; Bowler and Crapo 2002)

the most prominent natural antioxidants, generally added in the food to improve the quality and shelf life of the products. The vitamin C is the water-soluble antioxidant vitamin commonly found in the citrus fruits and vegetables. While the vitamin E is the fat-soluble vitamin commonly found in fruits rich in lipids viz. peanut oil, olive oil, sunflower oil, vegetables and in the livestock products such as meat, fish and milk. In this chapter, the discussion is focused on the antioxidants obtained from natural sources, i.e. natural antioxidants.

2.5 Importance of Natural Antioxidants

Natural antioxidants are widely distributed in food and medicinal plants. Among the wide category of natural antioxidants, polyphenols are the dominant plant molecules with potent antioxidant activity. In addition, the antioxidants play a crucial role as anticarcinogenicity, antimutagenicity, antiallergenicity and antiaging agents. The antioxidants from vegetable sources are mainly polyphenols (phenolic acids, anthocyanins, flavonoids, stilbenes and lignans), carotenoids viz. xanthophylls and carotenes, vitamins E and C. The importance of antioxidants is not limited to the food industry but for other oxidizable products, such as pharmaceuticals, cosmetics and plastics also. The development of natural antioxidants by plant cells is the defensive mechanism in response to the constant oxidative stress. These natural antioxidants inhibit the production of lipid oxidation catalysts, free radicals, oxidation intermediates and secondary breakdown products (Iacopini et al. 2008; Brown and Kelly 2007; Nakatani 2003). The antioxidants scavenge free radicals and inhibit Fe^{+3}/AA-induced oxidation (Ozsoy et al., 2009). Perhaps, this might be the reason that people started to use spices and herbs for the taste and flavour along with immunity strengthening of the body in the ancient period. Practising spices and herbs is a good approach but should be within the healthy limit. India is one of the countries where people use spices and herbs while making food. As discussed earlier, antioxidants are the compounds that delay autoxidation by inhibiting formation of free radicals or by interrupting propagation of the free radical by different mechanisms (Brewer 2011). Need is the mother of all inventions. Whenever human being faced problems in the back ancient era, every time they tried to find the appropriate and sustainable solution of the respective problem. The toxic effects of synthetic antioxidants actually paved the way to find antioxidants of natural origin with reasonable antioxidant potential (Ramalakshmi et al. 2008). Natural antioxidants are the molecules with greater bioavailability and lesser toxic effects unlike the synthetic antioxidants in the human body. Among the wide range of natural antioxidants, the phenolic compounds is the major category that is present in all parts of plants viz. roots, leaves, stems, bark and fruits (Asif 2015). Instead of terrestrial sources, the researchers have also claimed the aquatic system viz. algae and seagrass as a source of natural antioxidants. The natural antioxidants are classified into a number of categories viz. polyphenols, minerals, vitamins, carotenoids, flavonoids, gingerol and curcumin (Anwar et al., 2018). The detailed discussion of natural antioxidants has been given in Fig. 2.2. The bioavailability of

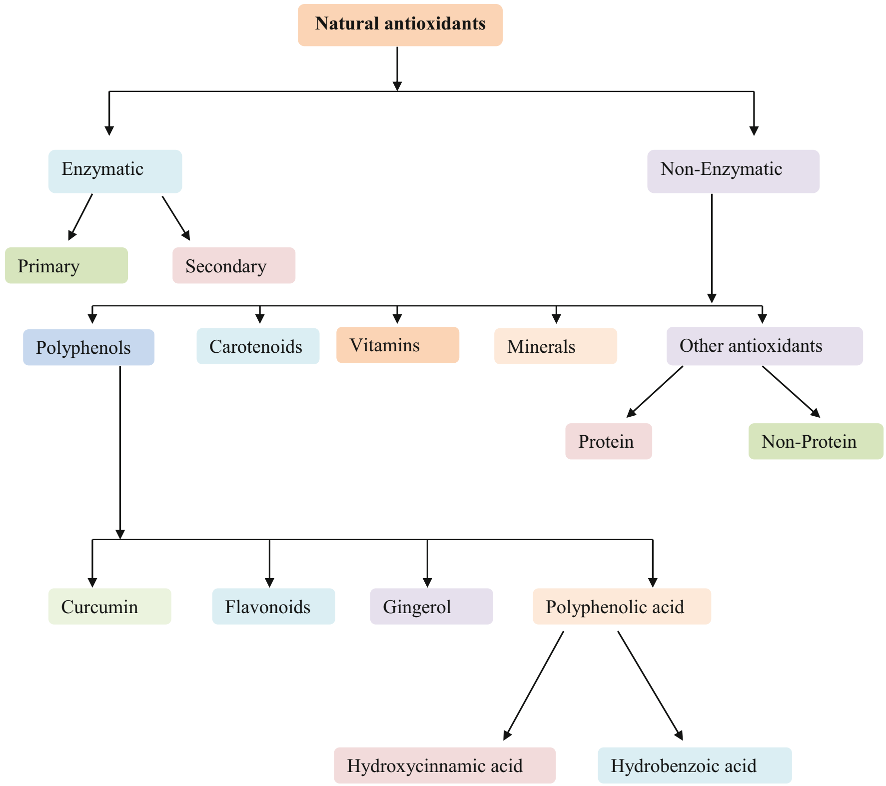


Fig. 2.2 Classification of natural antioxidants (source: Anwar et al. 2018)

vitamin E is comparatively greater than vitamin C, which is probably due to the fat solubility of vitamin E unlike vitamin C (Daniel 1986). Today, people are moving towards organic solution at the place of conventional method. The pharmaceuticals are increasing the load in human body and putting human at greater risk of organ failure. So many pharmaceutical companies are manufacturing encapsulated natural antioxidants to provide nutraceutical in pursue of sustainable health of mankind. There are variety of antioxidants present in the nature in different plant parts viz. fruits and vegetables. Ascorbic acid is naturally present in citrus fruits, Catechins in apples, beans, etc. The detailed description of natural antioxidants and their respective sources has been presented in Table 2.1.

2.6 Requirement of Antioxidants for Human Body

The daily intake of antioxidants is important to take through diet to get the balanced and healthy metabolism. The balance between the oxidants (free radicals) and antioxidants is necessary for the normal healthy life. The natural antioxidants can

Table 2.1 List of natural antioxidants and their sources

Natural antioxidants	Sources
Ascorbic acid	Citrus fruits, tomatoes, vegetables, brown rice, pink and red wine, mango, papaya, sweet potato, watermelon
Catechins	Apples, beans, berries, wine, tea, fruits, chocolate
Anthocyanins	Beets, berries, egg plant, grape fruits, pink and red wine
Beta-carotene	Vegetables, tomatoes, carrots, sweet potatoes, apricots, papayas, squash, acorn, peaches, bell peppers, broccoli, mango
Polyphenols	Tea, fruits, vegetables, red cabbage, blue and black berries
Lycopene	Tomatoes, papaya, watermelon, guava, pink and red grapes.
Tocopherol	Cooking oils (olive, sunflower, safflower and canola), almonds, hazelnuts, whole grains, and wheat germ
Lutein	Corn, egg
Selenium	Carrots, chicken, garlic, onions, oat meal, salmon, tuna, seafood, whole grains, wheat germ

Source: Alok et al. (2014); Cieślik et al. (2006)

Table 2.2 Recommended daily intake of some important antioxidants

Natural antioxidants	Recommended daily allowance	
	Infants	Adults
Vitamin E	4–7 μg/day	11–15 μg/day
Vitamin C	40–60 mg/day	60–80 mg/day
Vitamin A	300–400 μg/day	700–900 μg/day
Epicatechin	—	82 mg/single dose
Quercetin	—	100 mg/single dose

Source: Mbah et al. (2019)

protect the human beings against a number of problems ultimately caused by oxidative stress. The heavy load of oxidants, i.e. reactive oxygen species and reactive nitrogen species, that deter the metabolism in human body is termed as oxidative stress. Generally the oxidative stress is supposed to increase by several cell activities and processes viz., mitochondrial activity, exposure of harmful chemicals such as pesticides, insecticides and other drugs, smoking, environmental pollution and consumption of processed foods. There are some activities that can be controlled at consumer level. Consequently, there are many things that add oxidation load, cannot be controlled at consumer level. So, it is quite essential to take sufficient amount of antioxidants through diet as to maintain the balance between oxidants and antioxidants. The recommended dietary allowance for vitamin C for non-smoking adult male and female is 60 mg/day as given in Table 2.2. The increase in intake of vitamin C is evidenced to reduce the frequency of chronic diseases such as cardiovascular diseases such as atherosclerosis (Schwartz et al. 2009; Jenner and Jenner 2009), heart failure (Ferrari et al. 2004), myocardial infarction (Sartorio et al. 2007), cancer and cataract (Carr and Frei 1999). The United States Food and Drug administration (FDA) has identified and approved vitamin C as one of the four important natural antioxidants. The other three natural antioxidants are vitamin E, vitamin A and selenium. FDA also stated the free radical scavenging activity of vitamin C to protect cells from damage caused by reactive oxygen species (Fed Regist 1997). According to a research, taking more than 490 mg/day of vitamin C reduced the risk of cataract by 75% (Jacques and Chylack 1991). The requirement of vitamin C increases with increasing age, i.e. the elderly people have comparatively greater requirement of vitamin C than the younger ones.

2.7 Bioaccessibility and Bioavailability of Antioxidants

Besides the potential of variety of antioxidants, it is important that antioxidants must be bioavailable to the human body to act upon accordingly. Generally, the antioxidants are prone towards the enzymatic action and subject to degradation during their passage of buccal cavity till the intestine. The antioxidants present naturally in the food matrix are comparatively resistant against the enzymatic action in the human body. This implies that food system is the good natural carrier to permeate the antioxidants in the cell, for instance antioxidants present in the food are more bioavailable rather than the antioxidants in the free form. In recent today, researchers are putting their efforts to improve the bioavailability of antioxidants in the body. The technology of encapsulation is being applied to improve the solubility and bioavailability of antioxidants, viz. microencapsulation and nanoencapsulation. The lipid-based nanoencapsulation system is used to enhance the efficacy of bio-availability and solubility of antioxidants and also preventing the unnecessary interaction with other components within the food matrix (Mozafari et al. 2006). The liposomes are the efficient carriers also for the drugs, bioactive agents and other nutrients, etc. (Khosravi-darani and Mozafari 2010). The bioavailability of natural antioxidants like carotenoids, polyphenols and other plant-derived antioxidants varies from oral to intestine (Abourashed 2013). The different classes of antioxidants were tested for their antioxidant activity and bioavailability. In this chapter, it is quite cumbersome to cover all the natural antioxidants to describe their antioxidant activity. Therefore, the antioxidant activity of carotenoids is described in this chapter to understand the principles of bioaccessibility and antioxidant activity of carotenoids. The antioxidant activity of carotenoids is documented as scavengers of reactive oxygen species (Yeum and Russell 2002). It is claimed that a little amount of dietary fat improves the bioavailability of carotenoids for gastrointestinal absorption. Consequently, a high amount of fatty acids may deter the bioaccessibility of carotenoids (Fernandez-Garcia et al. 2012). In many other researches, it was found that the bioavailability of carotenoids also depends upon the genetic variability among the human beings (Borel 2012). There are various factors that control the absorption or bioavailability of carotenoids (Castenmiller and West 1997; West and Castenmiller 1998) as shown in Fig. 2.3.

Among the above-mentioned factors, food matrix, absorption modifiers and food preparation method are the most investigated factors that control the bioavailability of carotenoids (Sharif et al. 2017). Also, the incorporation of oil improves the bioavailability of carotenoids in the human beings (Sharif et al. 2017). In a study,

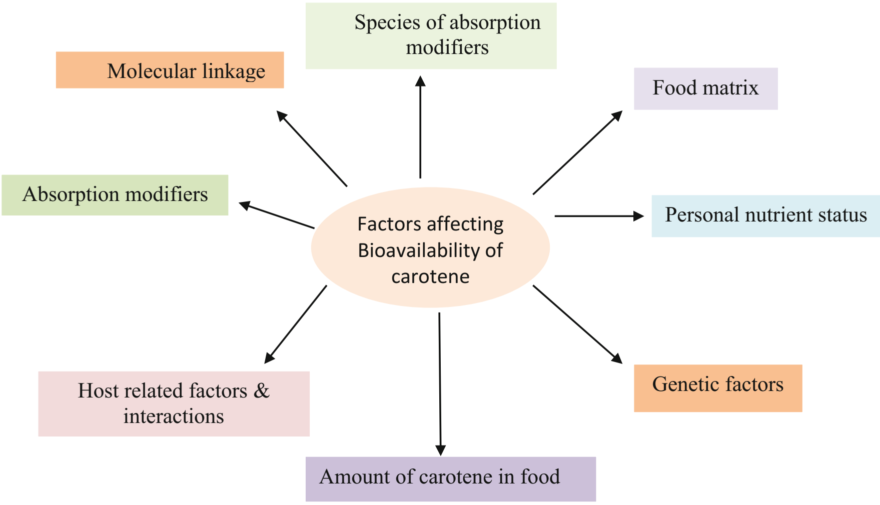


Fig. 2.3 Factors affecting the bioavailability of carotene

raisin supplementation was found to affect the bioavailability of phenolic compounds and also enhance the resistance of serum against oxidation in healthy subjects (Kanellos et al. 2013). In the recent today, people are amulgating the different frontier technologies to enhance the bioavailability and delivery of dietary components (Sharif et al. 2017). Nanotechnology is the most promising technology that claims the different behaviour of molecules at molecular size in the range of 1–100 nm. Today, the application of nanotechnology is helping out by providing the sustainable solution in various disciplines of science and technology. In the field of food and pharmaceuticals, the bioavailability and delivery are the main and limiting factor in the development of drugs, food and nutraceutical.

2.8 Conclusion

Natural antioxidants are required by human body for the normal functioning of metabolic processes and is therefore essential to take daily through diet. The deficiency of antioxidants leads to number of diseases that may cause death in severe condition. The studies of oxidative biomarker suggested the importance of natural antioxidants such as vitamin C, vitamin E and vitamin A. In several studies, it was found that the significant dose of natural antioxidants significantly reduced the mortality rate. It is suggested to consumers to take plenty of fruits and vegetables to fulfil the daily requirement of antioxidants to reduce the risk of diseases caused by oxidative stress.

References

Abourashed EA (2013) Bioavailability of plant-derived antioxidants. Antioxidants 2:309–325. https://doi.org/10.3390/antiox2040309

Alkadi H (2018) A review on free radicals and antioxidants. Infect Disord Drug Targets. https://doi.org/10.2174/1871526518666180628124323

Alok SH et al (2014) Herbal antioxidant in clinical practice: A review. Asian Pac J Trop Biomed 4 (1):78–84

Anbudhasan P, Surendraraj A, Karkuzhali S, Sathishkumaran S (2014) Natural antioxidants and its benefits. Int J Food Nutr Sci 3(6)

Anwar H, Hussain G, Mustafa I (2018) Antioxidants from natural sources (Chap-1a). In: Shalaby E, Azzam GM (eds) Antioxidants in foods and its applications. IntechOpen, pp 3–28. https://doi.org/10.5772/intechopen.75961

Asif M (2015) Chemistry and antioxidant activity of plants containing some phenolic compounds. Chem Int 1(1):35–52

Aslani BA, Ghobadi S (2016) Studies on oxidants and antioxidants with a brief glance at their relevance to the immune system. J Life Sci 146:163–173. https://doi.org/10.1016/j.lfs.2016.01.014

Borel P (2012) Genetic variations involved in interindividual variability in carotenoid status. Mol Nutr Food Res 56:228–240

Bowler RP, Crapo JD (2002) Oxidative stress in allergic respiratory diseases. J Allergy Clin Immunol 110:349–356

Brewer MS (2011) Natural antioxidants: sources, compounds, mechanisms of action, and potential applications. Compr Rev Food Sci Food Safety 10. https://doi.org/10.1111/j.1541-4337.2011.00156.x

Brown JE, Kelly MF (2007) Inhibition of lipid peroxidation by anthocyanins, anthocyanidins and their phenolic degradation products. Eur J Lipid Sci Technol 109(1):66–71

Carr AC, Frei B (1999) Toward a new recommended dietary allowance for vitamin C based on antioxidant and health effects in humans. Am J Clin Nutr 69(6):1086–1107. https://doi.org/10.1093/ajcn/69.6.1086

Castenmiller JJM, West CE (1997) Bioavailability of carotenoids. Pure Appl Chem 69:2145–2150

Cieślik E et al (2006) Content of polyphenols in fruit and vegetables. Food Chem 94:135–142

Daniel J (1986) Metabolic aspects of antioxidants and preservatives. Xenobiotica 16 (10-11):1073–1078

Fed Regist (1997) Food labeling; nutrient content claims: definition for "high potency" and definition of "antioxidant" for use in nutrient content claims for dietary supplements and conventional foods. Docket no. 95N-0347. Office of the Federal Register, National Archives and Records Administration 62:49868–49881.

Fernandez-Garcia E, Carvajal-Lerida I, Jaren-Galan M, Garrido-Fernandez J, Perez-Galvez A, Hornero-Mendez D (2012) Carotenoids bioavailability from foods: From plant pigments to efficient biological activities. Food Res Int 46:438–450

Ferrari R, Guardigli G, Mele D, Percoco GF, Ceconi C, Curello S (2004) Oxidative stress during myocardial ischaemia and heart failure. Curr Pharm Design 10:1699–1711

Hillmann J (2010) Reformulation key for consumer appeal into the next decade. Food Rev 37 (1):18–19

Iacopini P, Baldi M, Storchi P, Sebastiani L (2008) Catechin, epicatechin, quercetin, rutin, and resveratrol in red grapes: content, in vitro antioxidant activity and interactions. J Food Compos Anal 21(8):589–598

Jacques PF, Chylack LT (1991) Epidemiologic evidence of a role for the antioxidant vitamins and carotenoids in cataract prevention. Am J Clin Nutr 53(Suppl):352S–355S

Jenner P, Jenner P (2009) Oxidative stress as a cause of Parkinson's disease. Acta Neurol Scand 84:6–15

Kanellos PT, Kaliora AC, Gioxari A, Christopoulou GO, Kalogeropoulos N, Karathanos VT (2013) Absorption and bioavailability of antioxidant phytochemicals and increase of serum oxidation resistance in healthy subjects following supplementation with raisins. Plant Foods Hum Nutr 68 (4):411–415. https://doi.org/10.1007/s11130-013-0389-2

Khosravi-darani K, Mozafari MR (2010) Nanoliposome potentials in nanotherapy: a concise overviewt. J Nanosci Nanotechnol 6(1):3–13

Mbah CJ, Orabueze I, Okorie NH (2019) Antioxidants properties of natural and synthetic chemical compounds: therapeutic effects on biological system. Acta Sci Pharm Sci 3(6). https://doi.org/10.31080/ASPS.2019.03.0273

Mozafari MR, Flanagan J, Matia-merino L, Awati A, Omri A, Suntres ZE, Singh H (2006) Recent trends in the lipid-based nanoencapsulation of antioxidants and their role in foods. J Sci Food Sci Agric 86(13):2038–2045. https://doi.org/10.1002/jsfa.2576

Nakatani N (2003) Biologically functional constituents of spices and herbs. J Jpn Soc Nut Food Sci 56(6):389–395

Ozsoy N, Yilmaz T, Kurt O, Can A, Yanardag R (2009) In vitro antioxidant activity of Amaranthus lividus L. Food Chem 116:867–872

Phaniendra A, Jestadi DB, Periyasami L (2015) Free radicals: properties, sources, targets, and their implication in various diseases. Ind J Clin Biochem 30(1):11–26. https://doi.org/10.1007/s12291-014-0446-0

Pizzino G, Irrera N, Cucinotta M, Pallio G, Mannino F, Arcoraci V, Squadrito F, Altavilla D, Bitto A (2017) Oxidative stress: harms and benefits for human health. Oxid Med Cell Longev:8416763, 13 p. https://doi.org/10.1155/2017/8416763

Ramalakshmi K, Kubra IR, Rao LJM (2008) Antioxidant potential of low-grade coffee beans. Food Res Int 41(1):96–103

Sartório CL, Fraccarollo D, Galuppo P, Leutke M, Ertl G, Stefanon I, Bauersachs J (2007) Mineralocorticoid receptor blockade improves vasomotor dysfunction and vascular oxidative stress early after myocardial infarction. Hypertension 50:919–925

Schwartz CJ, Valente AJ, Sprague EA, Kelley JL, Nerem RM (2009) The pathogenesis of atherosclerosis: An overview. Clin Cardiol 14:1–16

Shammas NK, Yang JY, Yuan PC, Hung YT (2005) Chemical oxidation. In: Wang LK, Hung YT, Shammas NK (eds) Physicochemical treatment processes, Handbook of environmental engineering, vol 3. Humana, Totowa

Sharif MK, Shah FH, Butt MS, Sharif HR (2017) Role of nanotechnology in enhancing bioavailability and delivery of dietary factors. Nutr Deliv. https://doi.org/10.1016/B978-0-12-804304-200015-9

Sonia N, Mini C, Geethalekshmi P (2016) Vegetable peels as natural antioxidants for processed foods–a review. Agric Rev 37(1):35–41

Valko M, Rhodes CJ, Moncol J, Izakovic M, Mazur M (2006) Free radicals, metals and antioxidants in oxidative stress-induced Cancer. Chem Biol Interact 160(1):1–40. Epub 2006 Jan 23

West CE, Castenmiller JJM (1998) Quantification of the "SLAMENGHI" factors for carotenoids bioavailability and bioconversion. Int J Vitam Nutr Res 68:371–377

Xu DP, Li Y, Meng X, Zhou T, Zhou Y, Zheng J, Zhang JJ, Li HB (2017) Natural antioxidants in foods and medicinal plants: extraction, assessment and resources. Int J Mol Sci 2017(18):96. https://doi.org/10.3390/ijms18010096

Yeum KJ, Russell RM (2002) Carotenoid bioavailability and bioconversion. Annu Rev Nutr 22:483–504

Probiotic Bacteria Used in Food: A Novel Class of Antibiofilm Agent

3

Fohad Mabood Husain, Nasser A. Abdulatif Al-Shabib, Abdullah Alyousef, Altaf Khan, Mohammed Arshad, Iftekhar Hassan, Thamer A. Albalawi, and Iqbal Ahmad

Abstract

Probiotics are live microorganisms or bacterial cultures that can have beneficial effects for the host when ingested. Probiotics must survive stressful conditions of the gastrointestinal tract by tolerating acid, bile, and gastric enzymes and must adhere to intestinal epithelial cells to colonize the gut. Moreover, probiotics should have antimicrobial effects against pathogenic microorganisms and desirable antibiotic susceptibility patterns. Many gastrointestinal diseases, such as diarrhea, irritable bowel syndrome, and chronic inflammatory bowel disease are caused by intestinal microflora imbalance, which is an important factor in bacterial translocation and infection. The current treatment of intestinal microbiota

F. M. Husain (✉) · N. A. A. Al-Shabib
Department of Food Science and Nutrition, Faculty of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia
e-mail: fhusain@ksu.edu.sa

A. Alyousef · M. Arshad
Department of Clinical Laboratory Sciences, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia

A. Khan
Department of Pharmacology and Toxicology, Central Laboratory, College of Pharmacy, King Saud University, Riyadh, Saudi Arabia

I. Hassan
Department of Zoology, College of Science, King Saud University, Riyadh, Saudi Arabia

T. A. Albalawi
College of Biology, Prince Sattam bin Andulaziz University, Alkharj, Saudi Arabia

I. Ahmad
Department of Agricultural Microbiology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_3

imbalance is using antibiotics; however, misuse or overuse of antibiotics contributes to resistance, which is one of the major public health problems worldwide. Another concern is the decreasing efficacy of antibiotics in treating human and animal infections because of the biofilm formation of pathogenic bacteria. Bacterial cells in biofilms are highly protected, less subjected to mutation, represent low metabolic activity, and become resistant to antibiotics. Therefore, the probiotic strains having both antimicrobial and antibiofilm properties may be expected to be therapeutically more effective. The antimicrobial probiotics having biofilm-dispersive properties can yield better clinical benefits as a therapeutic agent. Keeping in focus the promise shown by probiotics, current review is aimed to highlight the antibiofilm potential of probiotic microorganisms against drug-resistant pathogens.

Keywords

Probiotics · Antibiofilm · Antimicrobial · Biofilm

3.1 Introduction

Live probiotic bacteria that we acquire through food are assumed to be beneficial to human health. Thus, probiotics can be defined as the "live microbial cells that provide health benefits to the hosts when given in sufficient numbers" (Reid et al. 2014). Global probiotics market is projected to reach a turnover value of US$ 46.55 billion by the year 2020. Most of the probiotic organisms have been recovered from the human gut and fermented foods such as pickles, yogurts, and kefir grains. Probiotics comprise of many different types of microbes that mainly include *Lactobacillus*, *Bifidobacterium*, and *Saccharomyces*. Other genera like *Bacillus*, *Propionibacterium*, *Streptococcus*, and *Escherichia* have also been exploited as probiotics. Scientific community is actively engaged in identifying more potential probiotic microbes from different sites of the healthy humans and use them for various health benefits (O'Toole et al. 2017). Probiotics have been shown to be effective in treating or preventing acute viral gastroenteritis, post-antibiotic associated diarrhea, allergic disorders of the children and diseases linked with bowel inflammation. Certain other potential applications of probiotics have been documented on the prevention and treatment of disease conditions like, cystic fibrosis, different types of cancers, urogenital infections, and dental disorders (Vuotto et al. 2014). Considering the ability of most pathogens to form resistant biofilms leading to persistent infections, probiotics could be an attractive agent to target biofilm inhibition.

Biofilms are complex communities of microbial cells that may be attached to a surface or reside as aggregates encapsulated in an extracellular matrix (Roy et al. 2018). Biofilm mode of lifestyle protects the microbe from harsh environments and are responsible for persistent infections. They are considered as causative agents of nosocomial infections in immune-compromised patients (Høiby et al. 2010). Most of nosocomial infections in patients are due to the biofilm formation on indwelling devices such as catheters, cardiac pacemakers and dentures. Surface of these devices is ideal for the attachment of microbial cells (Wu et al. 2015). Biofilm protect the bacteria from the host immune system and increase their resistance against antimicrobial drugs (Høiby et al. 2010). Biofilm formation by pathogens does take place at a rapid pace in food industry environments. Biofilm structures have been observed on artificial surfaces like stainless steel, wood, glass, polyethylene, and rubber (Khan et al. 2017). Ill effects of biofilm in food industry relate not only to its pathogenicity but also cause corrosion of metal surfaces, changes in organoleptic properties due to secretion of lipases and proteases. These effects are important in many of the food-based industries as various processes and structures serve as surface substrates for the development of biofilm at different temperatures for different microbial species (Mizan and Jahid 2015). Furthermore, the genes associated with the formation of biofilm in a species can have genomic variations which may lead to the establishment of completely different biofilm under different conditions. This, along with the diversity of the affected environment and different types of pathogens colonizing the biofilm, makes its eradication a herculean task (Galié et al. 2018).

In vitro studies on the various biological properties like adhesion, antibiotic production, growth inhibition has suggested a promising role of probiotics in the modulation of microbial biofilms (Vuotto et al. 2014). Biofilm-forming probiotic bacteria have the ability to be more thermo-tolerant and resist freeze-drying temperature (Cheow and Hadinoto 2013), and replace the pathogenic biofilm with a non-pathogenic bacteriocin-producing variant (Jones and Versalovic 2009; Samot et al. 2011). Despite this, very limited information is available on the biofilm control by probiotics, and extensive studies are needed to unravel novel probiotics with broad-spectrum antibiofilm potential. Therefore, in the current review, we aim to summarize various reports published on the biofilm inhibitory potential of probiotic strains.

3.2 Biofilm Formation

Formation of biofilm involves three main stages, first is the attachment stage followed by the formation of microcolonies by assembly of cells and finally the maturation of the biofilm. Mature differentiated biofilms are dispersed through mechanical and active processes (Boles and Horswill 2008). Adhesion of the microbe is governed by Lifshitz-Van der Waals, acid-base, hydrophobic, and electrostatic interaction (Van Oss et al. 1986). Various surface-associated proteins like OmpA, fibronectin-binding proteins (FBP), protein A, SasG, and biofilm-associated proteins (BAP) play a key role in the formation of biofilm especially in the initial stages (Roy et al. 2018). Quorum sensing (QS), a density-dependent cell–cell communication system is vital for the colonization of the bacteria for the formation of biofilm. Establishment of biofilm is often QS-regulated phenotype (Fuqua et al. 1994). Cells residing in the biofilm mode are enclosed extracellular matrix comprising a mixture of various biological macromolecules like protein, polysaccharides and nucleic acids and lipids. This matrix provides protection to the biofilm from harsh environmental conditions and confers drug resistance by preventing the entry of antimicrobials and also resists the attack of host immune system (Anderl et al. 2000).

Second stage in the biofilm development is an irreversible stage and starts with the secretion of exopolysaccharides (EPS). This secretion of EPS continues till the bacteria is firmly attached to the surface inside the complex matrix (Lappin-Scott and William Costerton 1989). Matured biofilm is tower-like 3D structures. These towers comprise of channels that help in the transport of nutrients, water, and waste, and small cavities present in the tower provide shelter for the planktonic bacteria. Organization and structure of the biofilm differ from one microbe to other, but no exact reason is known for this differentiation. However, biofilm formation in *P. putida* is governed by adhesion protein LapA (Gjermansen et al. 2010) while in other pseudomonads including *P. aeruginosa*, exopolysaccharides Pel and Psl are responsible for the formation of biofilm (Jackson et al. 2004; Matsukawa and Greenberg 2004). Hence, the variations in the components of the matrix may be responsible for the differences in the biofilm structure. Finally, the tower-like structures erode or sloughed off and get detached to release fresh bacteria in the environment (Purevdorj-Gage et al. 2005).

Recent studies on various bacteria has shown the role of c-di-GMP, an intercellular secondary messenger, in the initiation of biofilm formation and virulence (Gjermansen et al. 2010; Wilksch et al. 2011; Chen and Chai 2012). c-di-GMP functions by binding to various receptors that includes enzymes, adaptor proteins, riboswitches, and transcription factors (Ryan et al. 2012). It is well documented that various transducers mechanism and environmental causes increase the level of c-di-GMP in the cell. This increase in the c-di-GMP levels not only primes the production of adhesins but also plays an important role in the secretion of extracellular matrix (Monds et al. 2007; O'Connor et al. 2012). Production of important components of *P. aeruginosa* extracellular matrix, like CdrA adhesion, alginate Pel and Psl, is regulated in a positive manner by c-di-GMP (Hickman et al. 2005; Borlee et al. 2010). In addition to c-di-GMP, small regulatory RNAs (sRNA) also play a key role in the formation of biofilm in many microbial species (Chambers and Sauer 2013).

3.3 Probiotics: Characteristics

According to the definition given by International Scientific Association of Probiotics and Prebiotics (ISAPP), a probiotic when administered, must be alive, have a health benefit and should be given in a sufficient number (Hill et al. 2014). A probiotic must be safe for use and must not be a mixture but a defined and identified strains. There is no requirement for probiotics to demonstrate properties in pre-clinical assessment. The source of probiotics, i.e. human or animal, is also not mentioned in the definition. These characteristics may be important for a particular application, but they may not be needed for another use. For example, a probiotic intended for oral use should be able to withstand transition from intestinal environment. Identification of probiotics does not require a particular set of tests, and this is scientifically justified as most of the test required for putative identification have not been validated (Flach et al. 2018).

Probiotics are not one substance, and as biological entities they have the potential to act in different directions. Probiotic strains exert their effects by modulating host immune system, interacting with gut microbes, producing organic acids, competitive exclusion, improving barrier function, manufacturing small molecules with systemic effect and production of enzymes (O'Toole and Cooney 2008). However, many gaps still exist in the knowledge about the possible mechanisms responsible for the beneficial effects of probiotics.

The modifications caused by probiotics in human gut microbiota have still not been understood well. It is well known that probiotics promote healthy microbiota composition, but probiotic strains are scarcely reported to positively impact the overall gut microbial communities beyond the transient increase in the strain consumed (Kristensen et al. 2016), and these strains do not last more than 2 weeks after the consumption (Sanders et al. 2018). Despite the transient nature of the probiotics and no changes in the microbiota during its consumption, health benefits are well reported suggesting that no colonization of gastrointestinal tract is needed for gaining health benefits.

3.4 Biofilm Inhibitory Potential of Probiotics

Considering the deleterious effect of microbial biofilms and the need for safe and stable antibiofilm agents. In this section, we explore the use of probiotics strains as effective biofilm inhibitors.

3.4.1 Inhibition of Bacterial Biofilm

Lactic acid bacteria (LAB) are the most studied probiotic bacteria, and several research groups have reported their biofilm inhibitory property. In a study, eight *Lactobacillus* strains isolated from the feces of infants were assessed for their antibiofilm potential. Probiotic strains *L. paracasei* DTA93 and *L. paracasei* DTA81 inhibited biofilm of *E. coli* and *Listeria innocua* (Tarrah et al. 2019). In another investigation, lactobacilli isolated from feces of healthy children were screened against *Vibrio* spp. biofilm. Culture supernatants of all the seven isolated lactobacilli reduced biofilm formation in *V. cholerae* by over 90%. Moreover, these isolates caused significant dispersion of preformed biofilm. In case of *V. parahaemolyticus*, five of the seven *Lactobacillus* isolates inhibited biofilm formation but had no effect on the dispersion of preformed biofilms (Kaur et al. 2018).

Probiotic strains (*Lactobacillus acidophilus* KACC 12419, *L. casei* KACC 12413, *L. paracasei* KACC 12427 and *L. rhamnosus* KACC 11953) were used to evaluate biofilm formation inhibition against pathogens (*Salmonella typhimurium* KCCM 40253 and *Listeria monocytogenes* KACC 12671). Cocultures of *L. paracasei* and *L. rhamnosus* reduced the biofilm cells of *L. monocytogenes* by more than threefolds (Woo and Ahn 2013). In another study, two *Lactobacillus* strains, namely *L. rhamnosus* EMCC 1105 and *L. gasseri* EMCC 1930, have also been reported for their antagonistic activity against biofilm formed by pathogenic bacteria. Cell-free supernatant (CFS) of the two probiotic strains demonstrated significant biofilm against mono and multi-species biofilm of *E. coli*, *P. aeruginosa*, and *S. aureus* (Aboulwafa et al. 2017). Zamani et al. reported that CFS of *L. plantarum* isolated from cheese disrupted biofilm formation as well as preformed biofilms of drug-resistant *P. aeruginosa*, *S. aureus*, and *E. coli* (Zamani et al. 2017). Cell-free supernatants (CFS) of six probiotic bacteria belonging to genus *Bifidobacterium* and *Lactobacillus* were tested against biofilm formed by multi-drug-resistant strains of *E. coli*. All the strains demonstrated varying levels of biofilm inhibition in the drug-resistant *E. coli* strains (Abdelhamid et al. 2018). In another study, five LAB isolated from the bovine udders were studied to remove and replace *S. aureus*, *S. xylosus*, and *S. epidermidis* biofilms. All the LAB showed considerable removal of staphylococcal biofilms, but only *L. rhamnosus* and *L. plantarum* could replace the biofilm of the pathogen with their own (Wallis et al. 2019).

Broad-spectrum biofilm inhibitory activity of a probiotic strain of *E. coli* i.e. *E. coli* Nissle 1917 (EcN) against food-associated pathogens was reported recently (Fang et al. 2018). EcN reduced biofilm formation in enterohemorrhagic *E. coli* (EHEC) by 14-folds, 1100 folds for *S. aureus* and 8300 folds for *S. epidermidis*. However, no effect was observed against the biofilm formed *by P. aeruginosa*. Secretion of extracellular DegP, a bifunctional periplasmic protein, was understood to be responsible for the antibiofilm potential of probiotic *E. coli*. There have been very less reports on the biofilm inhibition in *Salmonella* spp. In a report published on the investigation of farm probiotics against biofilm of *Salmonella*, it was observed that both autoclaved and non-autoclaved filtrates of probiotics showed the strongest biofilm inhibitory activity at a specific concentration of 0.001 A ($A = 1 \times 10^9$ bacterial/ml). It was also observed that higher concentration of filtrate did not demonstrate higher biofilm inhibition (Lee and Kim 2019). In another study, a total of six probiotic strains were isolated from commercial probiotic products and tested for their antibiofilm potential against *Cronobactersakazakii*. CFS of the isolated probiotic cultures showed higher biofilm inhibition at initial stages and the activity got reduced upon longer incubation (up to 48 h), indicating that the CFS might be acting on the attachment stage of the biofilm formation (Jamwal et al. 2019).

Biosurfactants derived from the probiotic strains have also been reported to obliterate pathogenic biofilms. In a recent study, biosurfactants isolated from *Lactobacillus acidophilus* NCIM 2903 demonstrated antibiofilm and antiadhesion activity against *B. subtilis* and *P. vulgaris* (Satpute et al. 2018). In another report, biosurfactant-producing bacteria were investigated for biofilm inhibitory potential against *E. coli* and *S. aureus*. Four of the biosurfactant-producing isolates reduced the biofilm formed by both the pathogenic bacteria. *L. plantarum* was the most promising isolate showing significant inhibitory activity against *E. coli* and *S. aureus* (Kaur et al. 2015).

Some recent reports have highlighted the promising biofilm inhibitory potential of the probiotics against oral bacteria and thus may play a key role in maintaining oral hygiene. Biofilm formation by *Streptococcus mutans* plays an important role in dental caries. Eight probiotic strains were screened to study their effect on *S. mutans* biofilm. *L. acidophilus* demonstrated highest activity among all tested probiotics, while *L. casei* showed significant retention of probiotics in the biofilm (Schwendicke et al. 2017). *Aggregatibacter actinomycetemcomitans* is an oral bacterium that contributes to periodontal diseases. Probiotic *Lactobacillus* spp. exhibited high reduction of mature biofilm formed by *A. actinomycetemcomitans* Y4 and OMZ 534 strain, while moderate activity was recorded against SUNY 75 strain. The biofilm activity of the probiotic strain is attributed to the lipase enzyme production (Jaffar et al. 2016). LAB, namely *Pediococcuspentosaceus* and *Lactobacillus brevis*, isolated from different food sources were able to inhibit biofilm formation of oral pathogens, *B. cereus* ($MBIC_{50} = 28.16\%$) and *S. salivarius* ($MBIC_{50} = 42.28\%$) (Ben Taheur et al. 2016). A recent study on three *Lactobacillus* strains (*L. kefiranofaciens* DD2, DD5, and DD6) isolated from kefir and three commercial *Lactobacillus strains* (*L. plantarum* ATCC 10012, *L. johnsonii* JCM 1022, and *L. rhamnosus* ATCC 7469) was conducted to determine the antibiofilm activity against dental-associated bacteria *S. mutans* and *S. sobrinus*. Isolated strain *L. kefiranofaciens* DD2 and commercial strains *L. plantarum*, *L. johnsonii*, and *L. rhamnosus* inhibited growth and biofilm of both *S. mutans* and *S. sobrinus*. In particular, *L. kefiranofaciens* DD2 suppressed the expression of biofilm-associated genes (Jeong et al. 2018). In another study on oral bacteria, *L. casei* and *L. reuteri* showed statistically significant inhibition of *S. mutans* (73.05%) and *P. gingivalis* (77.97%) biofilm in vitro.

3.4.2 Inhibition of *Candida* biofilm

Candidiasis manifestations are associated in way or other with the formation of *Candida* biofilms on inert or biological surfaces. Probiotic bacteria have been considered as potential preventive agents of *Candida* biofilms, and some reports have emerged describing the antibiofilm action. Probiotic *L. rhmanosus* and *L. reuteri* strains were observed to cause complete inhibition of *C. glabrata* biofilm. Biofilm-related genes of *C. glabrata EPA6* and*YAK1* were downregulated in response to the addition of probiotic strains (Chew et al. 2015). James et al. assessed the ability of three probiotic strains, namely *L. plantarum* SD5870, *L. helveticus* CBS N116411, and *S. salivarius* DSM 14685 to inhibit and disrupt *Candida albicans* biofilm. Co-incubation with probiotic supernatants under hyphae-inducing conditions reduced *C. albicans* biofilm formation by >75% in all treatment groups. Likewise, combinations of live probiotics reduced biofilm formation of *C. albicans* by >67%. When live probiotics or their supernatants were overlaid on preformed

C. albicans biofilms, biofilm size was reduced by >63% and >65%, respectively. Quantitative real-time PCR results indicated that the combined supernatants of SD5870 and CBS N116411 significantly reduced the expression of several *C. albicans* genes involved in the yeast–hyphae transition: ALS3 (adhesin/invasin) by 70% ($P < 0.0001$), EFG1 (hyphae-specific gene activator) by 47% ($P = 0.0061$), SAP5 (secreted protease) by 49% ($P < 0.0001$) and HWP1 (hyphal wall protein critical to biofilm formation) by >99% ($P < 0.0001$) (James et al. 2016). In a recent report, a novel probiotic was evaluated to prevent and treat polymicrobial biofilms (PMB) formed by *Candida tropicalis* with *E. coli* and *S. marcescens*. The probiotic filtrate amended *Candida tropicalis* PMB showed diminished biofilm matrix, reduced biofilm thickness and inhibited hyphal formation (Hager et al. 2019).

3.5 Conclusion

Increasing interest in the use of natural products for health benefits has created a boom in the field of probiotic research leading to the production of overwhelming number of products. To date, clinical confirmations have been obtained on the relevance of the relationship between immune system and probiotic microorganisms in protecting the host from colonization by pathogenic species. In fact, probiotics produce a variety of substances, ranging from relatively nonspecific fatty acids and peroxides to highly specific bacteriocins, which have been widely demonstrated to inhibit or kill other potentially pathogenic bacteria. However, the research is still in its infancy to look at probiotics as agents that can prevent biofilm formation and or disperse preformed biofilms of pathogenic bacteria. Further, in-depth analysis is needed to uncover the exact mechanism of biofilm inhibition by probiotics.

Acknowledgment The authors are grateful to the Deanship of Scientific Research, Research Centre, The College of Applied Medical Sciences, King Saud University, for funding this research work.

References

Abdelhamid AG, Esaam A, Hazaa MM (2018) Cell free preparations of probiotics exerted antibacterial and antibiofilm activities against multidrug resistant E. coli. Saudi Pharm J 26:603–607. https://doi.org/10.1016/j.jsps.2018.03.004

Aboulwafa M, Osama D, Elkhatib W et al (2017) Antimicrobial, antibiofilm and immunomodulatory activities of Lactobacillus rhamnosus and Lactobacillus gasseri against some bacterial pathogens. Int J Biotechnol Wellness Ind 6:12–21. https://doi.org/10.6000/1927-3037.2017.06.01.2

Anderl JN, Franklin MJ, Stewart PS (2000) Role of antibiotic penetration limitation in Klebsiella pneumoniae biofilm resistance to ampicillin and ciprofloxacin. Antimicrob Agents Chemother 44:1818–1824. https://doi.org/10.1128/AAC.44.7.1818-1824.2000

Ben Taheur F, Kouidhi B, Fdhila K et al (2016) Anti-bacterial and anti-biofilm activity of probiotic bacteria against oral pathogens. Microb Pathog 97:213–220. https://doi.org/10.1016/j.micpath.2016.06.018

Boles BR, Horswill AR (2008) agr-mediated dispersal of Staphylococcus aureus biofilms. PLoS Pathog 4. https://doi.org/10.1371/journal.ppat.1000052
Borlee BR, Goldman AD, Murakami K et al (2010) Pseudomonas aeruginosa uses a cyclic-di-GMP-regulated adhesin to reinforce the biofilm extracellular matrix. Mol Microbiol 75:827–842. https://doi.org/10.1111/j.1365-2958.2009.06991.x
Chambers JR, Sauer K (2013) Small RNAs and their role in biofilm formation. Trends Microbiol 21:39–49. https://doi.org/10.1016/j.tim.2012.10.008
Chen Y, Chai Y, Guo JH, Losick R (2012) Evidence for cyclic Di-GMP-mediated signaling in Bacillus subtilis. J Bacteriol 194:5080–5090. https://doi.org/10.1128/JB.01092-12
Cheow WS, Hadinoto K (2013) Biofilm-like Lactobacillus rhamnosus probiotics encapsulated in alginate and carrageenan microcapsules exhibiting enhanced thermotolerance and freeze-drying resistance. Biomacromolecules 14:3214–3222. https://doi.org/10.1021/bm400853d
Chew SY, Cheah YK, Seow HF et al (2015) In vitro modulation of probiotic bacteria on the biofilm of Candida glabrata. Anaerobe 34:132–138. https://doi.org/10.1016/j.anaerobe.2015.05.009
Fang K, Jin X, Hong SH (2018) Probiotic Escherichia coli inhibits biofilm formation of pathogenic E. coli via extracellular activity of DegP. Sci Rep 8:1–12. https://doi.org/10.1038/s41598-018-23180-1
Flach J, van der Waal MB, van den Nieuwboer M et al (2018) The underexposed role of food matrices in probiotic products: reviewing the relationship between carrier matrices and product parameters. Crit Rev Food Sci Nutr 58:2570–2584. https://doi.org/10.1080/10408398.2017.1334624
Fuqua WC, Winans SC, Greenberg EP (1994) Quorum sensing in bacteria: the LuxR-LuxI family of cell density- responsive transcriptional regulators. J Bacteriol 176:269–275. https://doi.org/10.1128/jb.176.2.269-275.1994
Galié S, García-Gutiérrez C, Miguélez EM et al (2018) Biofilms in the food industry: health aspects and control methods. Front Microbiol 9:1–18. https://doi.org/10.3389/fmicb.2018.00898
Gjermansen M, Nilsson M, Yang L, Tolker-Nielsen T (2010) Characterization of starvation-induced dispersion in Pseudomonas putida biofilms: genetic elements and molecular mechanisms. Mol Microbiol 75:815–826. https://doi.org/10.1111/j.1365-2958.2009.06793.x
Hager CL, Isham N, Schrom KP et al (2019) Effects of a novel probiotic combination on pathogenic bacterial-fungal polymicrobial biofilms. MBio 10:1–11. https://doi.org/10.1128/mBio.00338-19
Hickman JW, Tifrea DF, Harwood CS (2005) A chemosensory system that regulates biofilm formation through modulation of cyclic diguanylate levels. Proc Natl Acad Sci U S A 102:14422–14427. https://doi.org/10.1073/pnas.0507170102
Hill C, Guarner F, Reid G et al (2014) Expert consensus document: The International Scientific Association for Probiotics and Prebiotics consensus statement on the scope and appropriate use of the term probiotic. Nat Rev Gastroenterol Hepatol 11:506–514. https://doi.org/10.1038/nrgastro.2014.66
Høiby N, Bjarnsholt T, Givskov M et al (2010) Antibiotic resistance of bacterial biofilms. Int J Antimicrob Agents 35:322–332. https://doi.org/10.1016/j.ijantimicag.2009.12.011
Jackson KD, Starkey M, Kremer S et al (2004) Identification of psl, a locus encoding a potential exopolysaccharide that is essential for Pseudomonas aeruginosa PAO1 biofilm formation. J Bacteriol 186:4466–4475. https://doi.org/10.1128/JB.186.14.4466-4475.2004
Jaffar N, Ishikawa Y, Mizuno K et al (2016) Mature biofilm degradation by potential probiotics: Aggregatibacter actinomycetemcomitans versus Lactobacillus spp. PLoS One 11:1–20. https://doi.org/10.1371/journal.pone.0159466
James KM, MacDonald KW, Chanyi RM et al (2016) Inhibition of Candida albicans biofilm formation and modulation of gene expression by probiotic cells and supernatant. J Med Microbiol 65:328–336. https://doi.org/10.1099/jmm.0.000226
Jamwal A, Sharma K, Chauhan R et al (2019) Evaluation of commercial probiotic lactic cultures against biofilm formation by Cronobacter sakazakii. Intest Res 17:192–201. https://doi.org/10.5217/ir.2018.00106

Jeong D, Kim DH, Song KY, Seo KH (2018) Antimicrobial and anti-biofilm activities of Lactobacillus kefiranofaciens DD2 against oral pathogens. J Oral Microbiol 10(1):1472985. https://doi.org/10.1080/20002297.2018.1472985

Jones SE, Versalovic J (2009) Probiotic Lactobacillus reuteri biofilms produce antimicrobial and anti-inflammatory factors. BMC Microbiol 9:1–9. https://doi.org/10.1186/1471-2180-9-35

Kaur S, Amrita KP, Nagpal R (2015) In vitro biosurfactant production and biofilm inhibition by lactic acid bacteria isolated from fermented food products. Int J Probiotics Prebiotics 10:17–22

Kaur S, Sharma P, Kalia N et al (2018) Anti-biofilm properties of the fecal probiotic Lactobacilli against Vibrio spp. Front Cell Infect Microbiol 8:1–14. https://doi.org/10.3389/fcimb.2018.00120

Khan AA, Sutherland JB, Khan MS, Abdullah S (2017) Location of biofilm and quorum sensing inhibitors. Food Preserv 439–463

Kristensen NB, Bryrup T, Allin KH et al (2016) Alterations in fecal microbiota composition by probiotic supplementation in healthy adults: A systematic review of randomized controlled trials. Genome Med 8(1):52. https://doi.org/10.1186/s13073-016-0300-5

Lappin-Scott HM, William Costerton J (1989) Bacterial biofilms and surface fouling. Biofouling 1:323–342. https://doi.org/10.1080/08927018909378120

Lee B, Kim SE (2019) Article the inhibitory effect of probiotics on the growth and biofilm formation of Salmonella sp. J Emerg Investig 2:1–7

Matsukawa M, Greenberg EP (2004) Putative exopolysaccharide synthesis genes influence. Society 186:4449–4456. https://doi.org/10.1128/JB.186.14.4449

Mizan MFR, Jahid IK, Ha SD (2015) Microbial biofilms in seafood: a food-hygiene challenge. Food Microbiol 49:41–55. https://doi.org/10.1016/j.fm.2015.01.009

Monds RD, Newell PD, Gross RH, O'Toole GA (2007) Phosphate-dependent modulation of c-di-GMP levels regulates Pseudomonas fluorescens Pf0-1 biofilm formation by controlling secretion of the adhesin LapA. Mol Microbiol 63:656–679. https://doi.org/10.1111/j.1365-2958.2006.05539.x

O'Connor JR, Kuwada NJ, Huangyutitham V et al (2012) Surface sensing and lateral subcellular localization of WspA, the receptor in a chemosensory-like system leading to c-di-GMP production. Mol Microbiol 86:720–729. https://doi.org/10.1111/mmi.12013

O'Toole PW, Cooney JC (2008) Probiotic bacteria influence the composition and function of the intestinal microbiota. Interdiscip Perspect Infect Dis 2008:1–9. https://doi.org/10.1155/2008/175285

O'Toole PW, Marchesi JR, Hill C (2017) Next-generation probiotics: the spectrum from probiotics to live biotherapeutics. Nat Microbiol 2. https://doi.org/10.1038/nmicrobiol.2017.57

Purevdorj-Gage B, Costerton WJ, Stoodley P (2005) Phenotypic differentiation and seeding dispersal in non-mucoid and mucoid Pseudomonas aeruginosa biofilms. Microbiology 151:1569–1576. https://doi.org/10.1099/mic.0.27536-0

Reid G, Jass J, Sebulsky MT, Mccormick JK (2014) Potential uses of probiotics in clinical practice. Clin Microbiol Rev 16:658–672. https://doi.org/10.1128/CMR.16.4.658

Roy R, Tiwari M, Donelli G, Tiwari V (2018) Strategies for combating bacterial biofilms: a focus on anti-biofilm agents and their mechanisms of action. Virulence 9:522–554. https://doi.org/10.1080/21505594.2017.1313372

Ryan RP, Tolker-Nielsen T, Dow JM (2012) When the PilZ don't work: effectors for cyclic di-GMP action in bacteria. Trends Microbiol 20:235–242. https://doi.org/10.1016/j.tim.2012.02.008

Samot J, Lebreton J, Badet C (2011) Adherence capacities of oral lactobacilli for potential probiotic purposes. Anaerobe 17:69–72. https://doi.org/10.1016/j.anaerobe.2011.04.001

Sanders ME, Merenstein D, Merrifield CA, Hutkins R (2018) Probiotics for human use. Nutr Bull 43:212–225. https://doi.org/10.1111/nbu.12334

Satpute SK, Mone NS, Das P et al (2018) Lactobacillus acidophilus derived biosurfactant as a biofilm inhibitor: A promising investigation using microfluidic approach. Appl Sci 8(9):1555. https://doi.org/10.3390/app8091555

Schwendicke F, Korte F, Dörfer CE et al (2017) Inhibition of Streptococcus mutans growth and biofilm formation by probiotics in vitro. Caries Res 51:87–95. https://doi.org/10.1159/000452960

Tarrah A, da Silva DV, de Castilhos J et al (2019) Probiotic potential and biofilm inhibitory activity of Lactobacillus casei group strains isolated from infant feces. J Funct Foods 54:489–497. https://doi.org/10.1016/j.jff.2019.02.004

Van Oss CJ, Good RJ, Chaudhury MK (1986) The role of van der Waals forces and hydrogen bonds in "hydrophobic interactions" between biopolymers and low energy surfaces. J Colloid Interface Sci 111:378–390. https://doi.org/10.1016/0021-9797(86)90041-X

Vuotto C, Longo F, Donelli G (2014) Probiotics to counteract biofilm-associated infections: promising and conflicting data. Int J Oral Sci 6:189–194. https://doi.org/10.1038/ijos.2014.52

Wallis JK, Krömker V, Paduch JH (2019) Biofilm challenge: lactic acid bacteria isolated from bovine udders versus Staphylococci. Foods (Basel, Switzerland) 8(2):79. https://doi.org/10.3390/foods8020079

Wilksch JJ, Yang J, Clements A et al (2011) MrKH, a novel c-di-GMP-dependent transcriptional activator, controls Klebsiella pneumoniae biofilm formation by regulating type 3 fimbriae expression. PLoS Pathog 7(8):e1002204. https://doi.org/10.1371/journal.ppat.1002204

Woo J, Ahn J (2013) Probiotic-mediated competition, exclusion and displacement in biofilm formation by food-borne pathogens. Lett Appl Microbiol 56:307–313. https://doi.org/10.1111/lam.12051

Wu H, Moser C, Wang HZ et al (2015) Strategies for combating bacterial biofilm infections. Int J Oral Sci 7:1–7. https://doi.org/10.1038/ijos.2014.65

Zamani H, Rahbar S, Garakoui SR et al (2017) Antibiofilm potential of Lactobacillus plantarum spp. cell free supernatant (CFS) against multidrug resistant bacterial pathogens. Pharm Biomed Res 3:39–44. https://doi.org/10.29252/pbr.3.2.39

4 Nutritional Modification in Meat Food for the Protection of Human Health

Saghir Ahmad and Irfan Khan

Abstract

Meat is a highly nutritious food and a source of good-quality proteins containing essential amino acids. The basic limitation of the meat is that it is devoid of dietary fibres. The diet free from dietary fibres may cause constipation problem which ultimately results in several metabolic disorders. Henceforth, it becomes essential to provide dietary fibres as well as minimize the fat in preparation of meat-based food. Vegetable and fruit wastes can provide supplement with good dietary fibres in meat food. There are variety of meat available in the market, viz. poultry, beef, sheep, lambs and veal. The nutritional modification of meat implies the processing of meat and meat products in such a way as to incorporate the functional value in the meat and meat products. Since the people are suffering with so many health problems related to high fat and high salt-rich meat products, it is the need of today to make low-fat and low-salt meat products to avoid the problems of atherosclerosis, arteriosclerosis, blood pressure, etc. Now a days, people have become aware enough about their health, hence the processors should make such meat products that carry nutritional adequacy and modified fatty acid profile. This chapter covers the processing of meat to make beneficial effects of human health by proper modification.

Keywords

Amino acids · Dietary fibres · Meat · Atherosclerosis

S. Ahmad (✉) · I. Khan
Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_4

4.1 Introduction

Meat has always been the highest choice amongst diet for the human. Meat has high-quality protein in combination with several vitamins and minerals and therefore most suitable for human consumption. Sensory properties of meat are highly appreciated, particularly the presence of myofibrillar protein which contributes to springiness, a unique texture character. The consumption of red meat has been limited to less than 500 g cooked red meat per week because of negative impact of meat consumption upon health (Grasso et al. 2014). In developed countries, wherein food of all types is abundant and cheap, the possible adverse effects of large amounts of fat from animal foods (described hereafter), the ongoing production of hygiene laws in slaughterhouses and the eventual processing of hormones are concerned.

A correlation between the consumption of processed red meat and the risk of colorectal cancer was identified by the World Cancer Research Fund in 2007. Though not given much clarification on the fact, the presumption was that excess fat, protein and iron and heat-processing compound (heterocyclic amines) were the cancer precursors. The other harmful agents in meat and meat products are microbial agents, pesticide residue, food additives like sodium chloride, nitrates and substances produced during meat processing. In meat products, trace amounts of chemical, pesticide and farm residues can be contained. As a product of the animal's reaction to chemical agents used in houses, pasturelands and fields, toxins, for example, could be administered directly to cattle containing insect or intestinal parasites, but may also be used in agriculture. Although there are not clear indications of the danger to the customer posed by these smaller amounts, they are considered a risk. This is why a large number of chemicals that can be found in meat are checked in compliance with universal regulations (Codex 1991A). Several epidémiologic research have shown a link to cancer in different areas such as the pancreas, colon, breast, prostate gland and endometrium between animal protein and cancer susceptibility. A review of 11 cases of colon cancer trials, three of stomach cancer and one of breast cancer have found that available information remains uncertain as to whether removing meat from the stomach would minimize the cancer risk (Phillips and Snowdon 1983). Cholesterol and carcinogenic compounds produced by certain lipid-processing processes in meat and meat products are hazardous to humans. Many lipid oxidation processes might be at least partially responsible for lipid negative effects. Depending on its concentration, circulation or accumulation in the human body, cholesterol may be desired or not in diet. In many other cases, food carrying high amount of cholesterol is limited because of the correlation of cholesterol-rich diet with coronary heart disease. Meat and meat products are among these foodstuffs (especially red meat). Coronary heart disease and saturated fatty acids have been a major cause of illnesses and mortality in areas of the industrialized world. Roughly 25% of saturated fatty acid is provided with animal fat in the diet, and meat intake itself is responsible over several diseases. Atherosclerosis indicates that the coronary arteries are impaired by accumulation of complex fatty mixes in the valves resulting in the occurrence of heart diseases. Thrombosis is a process in which blood clot formation occurs which blocks the narrowed arteries, it is fatal. However, if thrombosis is not fatal but reduces blood flow to heart muscle leads to the shortage of oxygen and it can lead to the sufficient damage, it is known as myocardial infection. There are several factors which may lead to coronary heart diseases including family history of CHD, smoking, lack of exercise, various type of stress and saturated fatty acid (Palmitic acid) in the diet. There are three types of lipoprotein in blood: low-density lipoprotein (LDL) where 46% of molecules is cholesterol; high-density lipoprotein (HDL) which has 20% cholesterol and very-low-density lipoprotein (VLDL) which have 8% cholesterol. Meat and its products are rich source of beneficial compounds: high-quality proteins, zinc, high bioavailable iron, magnesium and selenium. There are several considerations for reduction of cholesterol level in meat and meat products: short-path molecular distillation; lecithin treatment; extraction by saponin, using cholesterol oxidase; supercritical carbon dioxide extraction. Some of these methods are non-selective, expensive and adequately researched. Application of cholesterol-lowering compound, like soy protein and phytosterols, is better suited method (Cohn et al. 2010).

Pesticide residues and food additives are commonly occurring in meat and believe to cause serious hazards. These two classes of compound however do not generally constitute serious problem as long as the processor is adding them in a balancing manner to meat products. Protein quality of the meat is dependent upon the availability of essential amino acids; most of the essential amino acids are present in meat. Eight of the 20 food amino acids are essential for adults and ten for children.

Dietary protein quality can be determined in several ways (FAD/WHO 1991), but generally, according to specifications, it is the percentage of the amino acids present in the product or diet. This was presented on a percentage basis in prior literature, but with the approval of the S.I. nomenclature system, it is expressed as a ratio. A ratio of 1.0 (100%) thus implies that the amino acids present in the dietary proteins are to the exact level required to meet human needs; a ratio of 05 implies that only half of the essential amino acids required are present in one (or more) of them. The protein content will be zero when an essential amino acid is totally absent.

Also, the intake of red meat is linked with increased incidence of diabetes and cardiovascular diseases. It is worth mentioning the use of animal fat in diets and their connection to heart conditions and associated circulatory disorders. Red meat has high level of cholesterol, which played a role in blocking coronary arteries of patients having cardiac diseases. It has already been proposed to reduce the circulatory cholesterol in the blood of high-risk heart patients by using unsaturated fatty acids in the form of vegetable oil. Some new studies have demonstrated that the occurrence of heart disease and animal fat content in diet is obviously not interrelated. This is confirmed by the fact that even when there is total absence of cholesterol in the diet, cholesterol is accumulated in the body (Pearson and Gillette 1997). There are many other factors for cardiovascular disorders, such as heredity, hypertension, alcohol, the consumption of sugar and lack of exercises. The meat food has important components of animal tissues, i.e. cholesterol which occurs either free (unesterified) or combined with a fatty acid. Common lean meat of pork, beef and lamb contains 70–75 mg cholesterol per 100 g, 90% being in the free form. Whereas liver and brain contain 300 and 200 mg per 100 g cholesterol, respectively.

In 1982, a report on “Diet Nutrition and Cancer” was published by the National Academy of Science which proposed involvement of dietary fat in human cancer. The same study has indicated that meat preservation by smoking and salt can also lead to rising cancer incidences.

4.2 Remedies and Reformulation of Meat Products

Modification and reformulation may be done in meat food to overcome the problems of cancer, coronary diseases, obesity and heart diseases. It is suggested that meat products with lower content of fat, cholesterol, NaCl and nitrites should be taken in formulation. The animal fat may be replaced by vegetable oils like canola oil, safflower oil and olive oil which provide health benefits to human. Many approaches for reducing the salt contents in meat products were documented as sodium consumption has negative impact and causes high blood pressure (Aburto et al. 2013), for example salt substitutes (KCl, $MgCl_2$, $CaCl_2$), application of flavour enhancer (yeast extract or monosodium glutamate) and the practising of new processing technologies (power ultrasound and high-pressure pulsing).

Nitrates and nitrites have several functions in meat product (de Oliveira et al. 2012; Bedale et al. 2016): Lipid oxidation gives specific colours to the product and provide antimicrobial activities. The reduction of nitrites leads to the addition of artificial antioxidants, colourants, or preservatives, e.g. polyphosphates are used for increasing the water-holding capacity resulting in good texture and poor cooking loss. Again their involvement in chronic diseases, cardiovascular diseases or obesity, phosphates tend to be substituted by carrageenan, citrate, or protein of different origins (milk and soybean) (Tapola et al. 2004; Alvarado and McKee 2007). The reduction of fat, particularly animal, will reduce the chances of obesity and cardiovascular disease. The replacement of animal fat by vegetable oil with enough unsaturated fatty acids will bring the health benefit in the meat products. The aroma perceived in case of substitution of fat mimic systems of great significance. Most of the aroma compounds are fat-soluble and therefore help in the vaporization of these compounds assisted by high temperature. However, if the fat mimic substance is used to reduce the fat level of meat product, it provides double benefit: (1) it avoids the risk of cardiovascular disease due to saturated fat, (2) it helps to release aroma compound which are easily vaporized and perceived strong. The reducing or replacing of fat from meat system in processed meat brings many changes in the product. It provides mouth feel which can be in terms of viscosity, body, fullness, lubricity, creaminess, juiciness, smoothness. Flavour is the most important factor among all the sensory attributes. Nutritional requirements are met to the consumer in meat as meat has balanced amount of good-quality protein, vitamins (particularly from B group) and important minerals like iron, zinc, magnesium and selenium. Both fat and water are carriers of fat-soluble and water-soluble vitamins. Fat plays a very pivotal role in bringing perception of flavour to the humans, fat brings mouth feel, richness, acts as precursor and also play a role of flavour masking. Fat act as precursor of flavour in combination with protein (amino acids and other components upon heating). Though the aroma components are volatile but the fat and fatty acid associated with them hidden up to certain range of temperature. When heating or cooking crosses the limit of temperature, the fat melts and this gives a sudden burst of flavour. This can be exemplified with the release of butter flavour. Judicious use of fat (low fat) and salt can be imparted for flavour development of meat product. Reduced fat system has comparatively less fat and more water. Because many volatile aroma molecules are more soluble in oil than in water, the aroma can be regarded as powerful, harsh and imbalanced. This may be probably due to increase in vapour pressure in proportion to fat removal. More volatile aroma substances are released and enhanced as the vapour pressure increases. On the other side, salt is water-soluble, with the increase in water content salt loses its savour and needs to be adjusted to provide a similar salt profile to a product. This is particularly essential because salt improves flavour and also gives a salty taste for health-conscious people as they seek low-sodium product. The problem of formulating low-fat meat product is compounded with low-salt product. While fat and water are solvent of flavour component, protein and carbohydrate absorb flavour. However, protein hydrolysates can be utilized as potentiators to increase flavour and minimize the amount of salt required to balance the flavour in low fat meat product. As potentiators, it can be used to increase the flavour and reduce the amount of salt needed to balance the taste in a low-fat meat product. Overall effect of these components will not bring any adverse effect on physico-chemical, texture and sensory characteristic of meat product. Other flavour enhancers such as monosodium glutamate, guanidine 5 monophosphate and inositol 5 monophosphate favour the reduction of the salt content and improve flavour in low-fat meat system. Fat mimic system comprise of thickening agent, soluble bulking agent and micro particulate. Thickening agents like starches, gum and hemicelluloses give lubricity and are swellable. Soluble bulking agent like polydextrose, polyols and low viscous hydrocolloids play role in controlling absorption. Microparticulates having diameter of less than 0.3 μm are not regarded as particulates but serve as ball bearings smoothing out the flow properties of the fat replacement system. They are water-insoluble, examples are microparticulated proteins, microcrystalline cellulose. Once employed as a fat-mimetic device, these ingredients can mimic several of the textured features of fat in low-fat foods. Many fermentable gums are produced possessing different features which can be useful for low-fat meat processing.

Hydrocolloids are thickening and bulking agents made from microcrystalline cellulose. They are long chain polymers mainly composed of carbohydrates. Many are soluble and swellable in the aqueous environment and give smooth and creamy features that resemble fat. They provide thick gel in aqueous system and possess stabilizing, emulsifying, whipping and encapsulating characteristics.

4.3 Alginates

Alginates which are extracted from a class of brown sea weed has gelling properties. They form irreversible gels in cold water in the presence of calcium ions. The characteristic of cold-water gel formation is distinct from the gums extracted from red sea weed. Their potential to develop cold gel on exposure to calcium carbonate has enabled them to form restructured meat. The irreversible gel-forming properties make them suitable and efficient in low-fat meat products that will be reheated.

Carrageenan: It is extracted from red seaweed. There are three types of carrageenan: Kappa carrageenan forms strong gel that can undergo syneresis, whereas iota carrageenan forms fragile elastic gel but not subjected to syneresis, both form thermally reversible gel. For controlling syneresis, both kappa and iota carrageenan are usually mixed. Third type, Lambda carrageenan does not form gel and therefore it has no application in meat product. Kappa carrageenan has been used in sectioned and formed meat, e.g. in turkey breast product. Due to US regulatory approval, it needed an additional binding agent to offset the low salt level 0.05–1.0%, i.e. common in turkey breast (Pearson and Gillette 1997). Because of its cold solubility and freeze–thaw durability, Iota carrageenan is suggested to be used in low-fat beef patties. Added salt is incorporated in fat to ensure that the solubilization of iota carrageenan is not compromised. In emulsion-type meat products, carrageenan is used with salts and phosphates to extract the myofibrillar protein prior to adding the carrageenan. To thicken the pickle and hold carrageen suspended before being injected, Xanthan gum may be applied to the Kappa Carrageenan. Xanthan gum solutions liquefies and viscosity falls rapidly when the pump's shear effect is encountered. They are most suitably brought in combination as dry mix with soluble dispersing agents such as dextrose. Carrageenan interacts synergistically with starches and other carbohydrate substances like konjac flour. They have excellency in low meat product and can be employed in fairly low concentrations (0.1–0.5%). Carrageenans interact with proteins, bind the water, enhance slicibility, improve sensitivity and release aroma elements easily. They solubilize when meat products are heated and form gels during cooling between 50 and 60 °C.

4.4 Starches

The properties of meat products are dependent on the origin of added starches. Waxy corn starch in which amylopectin (branched chain) is in greater quantity has natural tendency to more fat-like feel than corn starch which has 74% amylose (linear chained). Waxy corn granules absorb water and swell quicker, giving a higher viscosity, but are more retrograde than dent corn starch. The starches of potato and tapioca are extremely bland with a smooth mouth feel, their gelatinisation temperature is lower.

There are several hydrocolloids and fat mimetic system that help as thickening agents, soluble bulking agents which maintain the texture, viscosity and stability of the meat products. They help to reduce total fat in the meat products.

Maltodextrins are formed by cleavage of amylose and amylopectin. They do not possess intact starch granules. In general, for low-fat meat products, maltodextrins with dextrose equivalents below 20 are used. They are cost-effective and easy to use and help to improve in holding water. Maltodextrins also play role in microbial inhibition by reducing the activity of water. They are limited to 3% in sausage products with standards of identity. There are many other types of hydrocolloids, viz. guar gum, locust bean gum, gallon gum and xanthan gum, which are used as a hydrochloride and form a gel when combined with each other. This property has been utilized in processed meat like bologna salami and pepperoni. It provides stability, impart smooth structure and assist in extrusion and stuffing. Several other types of hydrocolloids are konjac flour, cellulose and cellulose derivatives, which are distinctly used to improve the elasticity, strength of gel and increase in the concentration of the product. Such gels can be used in the processed meat to imitate the feel of ground fat. Cellulose derivatives are carboxymethyl cellulose (CMC), methyl cellulose (MC), carboxylethyl cellulose (CEC), hydroxypropylmethyl cellulose (HPMC) and microcrystalline cellulose (MCC). These cellulose derivatives found in most plants have water-binding capacity and therefore impart different characteristics to meat products. They form gel upon heating but not on cooling. This property enhances their potential to be used in meat products. They remain firm when they are heated as well as when cold. They cultivate suitability to microwave application for use in fat food. As they create an oil absorption barrier, which delay the loss of natural moisture. They provide better adhesion properties for breading having microparticulate structure impart some fat mouth feel to meat products. Methyl cellulose (at 0.15%) helps to improve binding strength and increased water-holding capacity in meat formulations.

Some protein products help to provide the water binding properties and act as a good hydrocolloid which can bind the great deal of water and soften the processed meat product, among them are gelatin, milk proteins and serum proteins. In cold water, swelling of gelatin occurs while in hot water it dissolves, gel formation occurs at 20 °C. This gel melts at 30 °C and thus will release flavour and can improve taste as the temperature of mouth is higher than 30 °C. Similarly milk protein albumin binds water, form gel and acts as a good emulsifier likewise serum albumin and fibrinogen excellent gelling protein and provides adhesive properties to meat products.

Some plant proteins also have peculiar properties of hydration and help to stabilize emulsion-type meat products. Soy concentrates (70%), soy flour (50%) and soy isolates (90%) are the three forms of soy products. The isolates are actually fat and carbohydrate-free and therefore they are most suitable to be used in low-fat meat products. The consumer has well accepted soy protein as ingredient. The isolates are also free from beany flavour and they are made very bland. Hydration of soy protein isolate is recommended with water in the ratio of 1:4. Combination of soy protein isolate in meat products provides good texture and imparts firmness.

Functional meat products play important role in providing health benefit and protect meat products from creating adverse effects on human health. The following methods are being suggested for meat products to make them functional:

(a) Reduced fat content in meat brings down fat and cholesterol content, improves fatty acid profile, reduces the risk of some common diseases such as obesity and hypercholesterolemia. (b) Improved dietary fibre in meat products enhances binding properties, cooking yield and textural profile, decreases caloric values, reduces the risk of gastrointestinal disorder, coronary heart disease, diabetes, obesity. (c) Products developed from lesser amount of sodium inhibit the risk of hypertension, reduce the risk of other diseases such as kidney stone, renal failure and cardiovascular disease. (d) Meat products enriched with natural antioxidants improve shelf life and lower TBARS (Thiobarbituric acid reactive substances) values.

The fibre is being the most important constituents of the food which is absent in meat. Another shortcoming in the products is the presence of saturated fat. Addition of fibre and several other functional ingredients will enhance the functional and nutritional value of the meat products.

Incorporation of dietary fibre: The plant-based derivatives like vegetables, fruits, herbs, nuts and spices are primarily used these days for the production of healthier and modified meat products having enhanced shelf life. The incorporation of dietary fibres and antioxidants is the major approach in new meat products development. The integration of fibres is in demand due to their technical use and their health benefits (Fisinin et al. 2009). The risk of obesity, colon cancer, cardiovascular disease and various other diseases was decreased with diets with a high proportion of dietary fibres (National Cancer Institute US Department of Health and Human Services 1984). Functional ingredients as fibre content in meat products are shown in Table 4.1. Several dietary fibres are being used as a possible fat replacement in meat products for the assessment of good health results (Mansour and Khalil 1997).

Fat oxidation in meat and meat products poses a severe problem of shelf unstability in meat. Meat fat contains good portion of phospholipids in its fat content. Meat is also a source of iron. Both phospholipids and iron are promoter of rancidity. Salt also promote rancidity. In all meat products, salt is often a constituent and therefore there are fair chances of the product getting rancid if all three factors prevail. The phenomenon of rancidity in case of meat and meat products often is indicated by warmed over flavour (WOF). Thus oxidation in meat due to the above factors lead to loss of quality particularly sensory and nutritional quality. Sensory qualities like taste, colour and texture are severely affected due to the fat oxidation. Free radicals produced by oxidation lead to the chain reaction associated with oxygen integration, and lipids, proteins, pigments and vitamins are the main targets in meat products (Johnson and Decker 2015). Antioxidants are used to prevent oxidation in meat products and preserve sensory attributes. Some of the antioxidants used in meat products are polyphosphates, butylated hydroxytoluene (BHT), sodium ascorbate and tocopherol acetate. Natural antioxidants are most preferred due to their nutritional advantage and also preventing the risk of oxidation. In the last two decades the natural antioxidants in meat products appear to be good substitute to reduce the consumption of synthetic additives since they are widely accepted by the people of the society. As these antioxidants are non-toxic and providing the functional properties beneficial to human health. Many

Table 4.1 Effects on various properties of meat products incorporate with different fibre sources

S. No.	Ingredients (functional) incorporated	Product as carrier	Results shown by the product developed
1	Pumpkin	Chicken sausages	Product showed fibre enrichment
2	Husk obtained from psyllium	Chicken patties	Reduction in fat cholesterol level coupled with dietary fibre enhancement
3	Rice bran in combination with flax seed oil	Beef patties	Reduction in both saturated fatty acid and total lipid
4	Lemon fibre combined with carrot fibre	Beef hamburger	Resulted in diminishing fat and cholesterol level
5	Flour of green banana mixed with soybean hulls	Chicken nuggets	Colour and texture improvement in addition to dietary fibre increment
6	Guava flour	Meat (sheep) nuggets	Boosting antioxidants level and dietary fibre
7	Fenugreek leaves flour with Psyllium husk	Meat (goat) patties	Boosting antioxidants level and dietary fibre
8	Rice flour with added gluten	Patties (beef)	Texture fairly improved
9	Tomato paste with added flax seed	Patties (beef)	Both fatty acid profile and nutrients were improved
10	Carrots with oats combination	Meat (chicken) cutlet	Higher moisture, lower free fatty acid
11	Flour (finger millet)	Patties (chicken)	Moisture retainment plus cooking yield enhancement

of synthetic antioxidants, viz. BHA and TBHQ, has been noted to show carcinogenic effect on human being, therefore many countries like Europe and USA has banned these antioxidants. The current industrial trend has shifted towards natural antioxidants such as sodium ascorbate, ascorbic acid, tocopherol acetate and various plant materials which are rich in radical scavenging polyphenols (Shahidi et al. 1992). In humans the antioxidants defence system includes enzymes (e.g. superoxide dismutase, catalase and glutathione peroxidase), copper- and iron-binding extracellular proteins (e.g. celluloplasmin, hactoglobin, albumin transferrin and lactoferrin), antioxidant vitamins (e.g. Vitamin C, vitamin E and beta carotene) and other cellular compounds (glutathione, quinone, uric acid and bilirubin) (Krinsky 1992). Furthermore, several exogenous phenolic compounds obtained from foodstuffs such as spices and herbs used in processed meat add to a pool of antioxidants (Jiang and Xiong 2015). Plant kingdom has been recognized as the most abundant source of antioxidants, e.g. being the spices, herbs and essential oils are rich in antioxidant. Sometimes they are used to improve the organoleptic or sensory characteristics of the meat product. Several fruits and vegetables are good source of antioxidants and other phytochemicals. Many plant leaves like tea leaves are excellent examples of plant antioxidants. Nature also has produced a series of multi-purpose short peptides, which can neutralize free radicals and chelate pro-oxidative metal ions. The later resulted in the preparation of natural antioxidant peptide by enzymatic protein hydrolysis.

One basic feature of such phenolics is the ability to break free radical chain reactions by hydrogen and electrons donation (Shahidi et al. 1992). Particularly rosemary extract, licorice extract, clove oil and black pepper are used as flavouring agents in processed meats. Most of the phenolic constituents are found in spices and herbs (e.g. gallic acid and caffeic acid). Rosemary extract is among the most approved and widely utilized natural antioxidants in the meat industry. Its antioxidant property is linked with the occurrence of various phenolic diterpenes, like carnosol, carnosic acid, rosmariquinone, rosmaridiphenol and rosmanol (Aruoma et al. 1992). Green tea extracts are used as nutraceutical supplements as natural antioxidants, antibacterial agents and antivirals. These extracts possess antimutagenic and anticarcinogenic activities (Yang and Landau 2000). The functional ingredients found in food material help to prevent several non-communicable diseases such as incorporation of fibre in meat product. Sources of fibre may be some fruits, vegetables, rice bran, flax seed, etc. Six examples are being cited regarding the discussion: (1) pumpkin rich in fibre had been incorporated in chicken sausage gives fibre-enriched product (Calvo et al. 2008). (2) Psyllium husk was added in chicken burger patties to enhance dietary fibre content and reduce cholesterol content (Savadkoohi et al. 2014). (3) Flax seed and rice bran were incorporated in beef burger patties to bring down the level of total lipid and saturated fatty acids (Johnson 1998). (4) Carrot and lemon fibre were added in beef and hamburger to reduce the fat and cholesterol content (Rodriguez-Amaya 2016). (5) Green banana and soybean flour were incorporated in chicken nuggets to improve dietary fibre and boost instrumental texture and colour characteristics (Sesso et al. 2003). (6) Guava was added in sheep meat nuggets to improve the antioxidants and dietary fibre. Antioxidants have been used in different types of meat products. These ingredients have functionality and had been obtained from different natural plant materials, e.g. in raw chicken meat, aqueous state of curry leaves and fenugreek leaves was used to improve the antioxidant activity of meat product (Chowdhury et al. 2001); clove powder was incorporated in chicken patties to impart antimicrobial property to the meat products; similarly, pomegranate rind powder was used in chicken patties to improve the antioxidant potential of the meat product; Guava, a good source of fibre and antioxidant, has been incorporated in sheep meat nugget to improve antioxidant property and provide dietary fibre. Natural antioxidants used to inhibit oxidation in processed meat products are given in Table 4.2.

Meat is though not essential part of diet, it attracts good population of society. Its consumption for better nutritional potential has been suggested by nutritionist as it contains good-quality protein, vitamins particularly B complex, and minerals like potassium, phosphorous, iron, zinc, magnesium and selenium. However, the diet of meat product has problems associated with excessive intake of saturated fatty acids, risk of food poisoning and several non-communicable diseases such as coronary heart disease (CHD) and blood pressure (BP). This has been created due to saturated

Table 4.2 Oxidation inhibition in meat products using different antioxidant (natural) sources

Antioxidant source	Prominent bioactive compound	Other bioactive compounds	Mechanism of antioxidant action	Meat products incorporated	References
Extracts of spices and herbs	Phenolic acids	Gallic, rosemarinic, casonic and caffeic acid	Through radical scavenging as well as metal chelation	Precooked pork and sausages	Jiang et al. (2013), Kong et al. (2010)
Extracts of fruits and leaves	Flavonoid, vitamin A,D, E,K	Procyanidins, quercetin, catechin	Radical scavenging only	Cooked patties (burger), pork patties (raw and cooked)	Ganhão et al. (2010), Jo et al. (2003)
Extracts of nuts and cereals	Tocopherols	Tocopherols (α-, β-, γ- and δ-)	Through radical scavenging	Steak (restructured), frankfurters	Cofrades et al. (2004), Jiménez-Colmenero et al. (2010)
Essential oils	Polyphenols	Eugenol, terpenoids	Through radical scavenging	Meat patties (Turkey), burgers (beef)	Loizzo et al. (2015), Sharafati-Chaleshtori et al. (2015)
Protein hydrolysates with peptides	Short chain peptides	Carnosine, Tyr-Phe-Glu, Tyr-Ser-Thr-Ala	Through radical scavenging coupled with metal chelation	Beef (cooked), patties (meat), meat emulsions, frankfurters	Cheng et al. (2014)

fatty acids, smoking, various type of stresses and certain disease associated together with a number of dietary factors.

Meat is highly regarded in the majority of countries and societies. Usually different forms of meat form the basis for celebrative and festive occasions and is seen as a food of high nutritional value from the traditional and also from the scientific perspective. A large number of people who are vegetarians and meat is not their essential diet, but to make the diet adequate they include the animal products so that a good diet is ensured. An energy-appropriate diet is almost always sufficient in protein, in both quality and quantity. The protein requirement of adult is 7–8% of total energy intake, and since most cereals contain 8–12% protein. Hence if the diet comprises of entirely cereal, the sufficient nutrients will be available to satisfy energy need and protein need at the same time. On special occasion the little high protein is required, e.g. pregnant women and nursing mother needs high protein requirements. In some of the diseases people either suffering from infection or intestinal parasites. In the relevant diseases the protein catabolism is enhanced. During stress conditions like fever, broken bone, burns and other traumas, there is considerable loss of protein, therefore it must be compensated by adequate nutritional diet.

Meat is a good source of all B-complex vitamins viz. thiamine, riboflavin, niacin, biotin, cyanocobalamin, pantothenic acid and folacin. Some organs (offals) contain good amount of Vitamins A, E and K which are absent in lean meat.

Amount of iron present in the food provides a source but its chemical form and presence of another ingredient decide about the absorption in the human body. Various physiological factors also decide to promote or inhibit the absorption of iron present in meat as haem iron, it is properly absorbed about 15–35%, while there is a poor absorption of iron from the plant food falling in the range of 1–10%.

4.5 Conclusion

Meat and meat products have excellent nutritional value and therefore are highly consumed by the large population of the world. There are certain limitations in using meat as red meat contains cholesterol which is harmful to the human health. Meat does not contain dietary fibre and therefore it may cause several cardiovascular diseases even colon cancer, due to constipation created by meat diet. The dietary fibre plays important role in improving digestibility, providing bulk in the intestine and help in movement of digestive matter in intestinal tract. Certain non-meat ingredients viz. vegetable protein dietary fibre, cereals by products, legumes, fruits, and lactic acid bacteria provide functionality to the meat. These ingredients provide health benefit by mediating specific physiological functions. Reformation and nutritional modification are achieved by the addition of dietary fibre, hydrocolloids and fat-mimicking substances. These constituents prevent gastrointestinal disorder, coronary heart disease, diabetes and obesity.

References

Aburto NJ, Ziolkovska A, Hooper L, Elliott P, Cappuccio FP, Meerpohl JJ (2013) Effect of lower sodium intake on health: systematic review and meta-analyses. Br Med J 346:1–20

Alvarado C, McKee S (2007) Properties and safety of poultry meat. J Appl Poult Res 16 (1):113–120

Aruoma OI, Halliwell B, Aeschbach R, Löligers J (1992) Antioxidant and prooxidant properties of active rosemary constituents: Carnosol and carnosic acid. Xenobiotica 22:257–268

Bedale W, Sindelar JJ, Milkowski AL (2016) Dietary nitrate and nitrite: benefits, risks, and evolving perceptions. Meat Sci 120:85–92

Calvo MM, Garcia ML, Selgas MD (2008) Dry fermented sausage enriched with lycopene from tomato peel. Meat Sci 2:167–172

Cheng Y, Chen J, Xiong YL (2014) Interfacial adsorption of peptides in oil-in-water emulsions costabilized by Tween 20 and antioxidative potato peptides. J Agric Food Chem 62:11575–11581

Chowdhury BK, Jha S, Bhattacharyya P, Mukherjee J (2001) Two new carbazole alkaloids from Murraya koenigii. Indian J Chem 40:490–494

Cofrades S, Serrano A, Ayo J, Solas MT, Carballo J, Jiménez-Colmenero F (2004) Restructured beef with different proportions of walnut as affected by meat particle size. European Food Research Technology 218:230–236

Cohn JS, Kamili A, Wat E, Chung RWS, Tandy S (2010) Reduction in intestinal cholesterol absorption by various food components: mechanisms and implications. Atheroscl Suppl 11 (1):45–48

Fisinin VI, Papazyan TT, Surai PF (2009) Producing selenium-enriched eggs and meat to improve the selenium status of the general population. Crit Rev Biotechnol 29(1):18–28

Ganhão R, Morcuende D, Estévez M (2010) Protein oxidation in emulsified cooked burger patties with added fruit extracts: influence on colour and texture deterioration during chill storage. Meat Sci 85:402–409

Grasso S, Brunton NP, Lyng JG, Lalor F, Monahan FJ (2014) Healthy processed meat products–regulatory, reformulation and consumer challenges. Trends Food Sci Technol 39(1):4–17

Jiang J, Xiong YL (2015) Role of interfacial protein membrane in oxidative stability of vegetable oil substitution emulsions applicable to nutritionally modified sausage. Meat Sci 109:56–65

Jiang J, Zhang X, True AD, Zhou L, Xiong YL (2013) Inhibition of lipid oxidation and rancidity in precooked pork patties by radical-scavenging licorice (Glycyrrhiza glabra) extract. J Food Sci 78:C1686–C1694

Jiménez-Colmenero F, Cofrades S, López-López I, Ruiz-Capillas C, Pintado T, Solas MT (2010) Technological and sensory characteristics of reduced/low fat, low-salt frankfurters as affected by the addition of konjac and seaweed. Meat Sci 84(3):356–363

Jo C, Son JH, Son CB, Byun MW (2003) Functional properties of raw and cooked pork patties with added irradiated, freeze dried green tea leaf extract powder during storage at 4°C. Meat Sci 64:13–17

Johnson EJ (1998) Human studies on bioavailability and plasma response of lycopene. Exp Biol Med 2:115–120

Johnson DR, Decker EA (2015) The role of oxygen in lipid oxidation reactions: a review. Annu Rev Food Sci Technol 6:171–190

Kong B, Zhang H, Xiong YL (2010) Antioxidant activity of spice extracts in a liposome system and in cooked pork patties and the possible mode of action. Meat Sci 85:772–778

Krinsky NI (1992) Mechanism of action of biological antioxidants. Proc Soc Exp Biol Med 200 (2):248–254

Loizzo MR, Tundis R, Menichini F, Duthie G (2015) Anti-rancidity effect of essential oils, application in the lipid stability of cooked Turkey meat patties and potential implications for health. International Journal of Food Science and Nutrition 66:50–57

Mansour EH, Khalil AH (1997) Characteristics of low-fat beef burger as influenced by various types of wheat fibers. Food Res Int 30:199–205
National Cancer Institute US Department of Health and Human Services, NIG Pub. 1984 85:2711
de Oliveira TLC, de Carvalho SM, de Araújo SR, Andrade MA, das Graças Cardoso M, Ramos EM, Hilsdorf Piccoli R (2012) Antioxidant effects of *Satureja montana* L. essential oil on TBARS and color of mortadella-type sausages formulated with different levels of sodium nitrite. LWT Food Sci Technol 45(2):204–212
Pearson AM, Gillette TA (1997) Processed meat, III edn. Chapman & Hall, New York, pp 81–85
Phillips RL, Snowdon DA (1983) Association of meat and coffee use with cancers of the large bowel, breast and prostate among seventh-day Adventists: preliminary results. Cancer Res 43:2403–2408
Rodriguez-Amaya DB (2016) Natural food pigments and colorant. Curr Opin Food Sci 7:20–26
Savadkoohi S, Hoogenkamp H, Shamshi K, Farahnaky A (2014) Color, sensory and textural attributes of beef frankfurter, beef ham and meat sausage containing tomato pomace. Meat Sci 97(4):410–418
Sesso HD, Liu S, Gaziano JM, Burning JE (2003) Dietary lycopene, tomato-based products and cardiovascular disease in women. J Nutr 133(7):2336–2341
Sharafati-Chaleshtori R, Rokni N, Rafieian-Kopaei M, Drees F, Salehi E (2015) Antioxidant and antibacterial activity of basil (Ocimum basilicum l.) essential oil in beef burger. J Agric Sci Technol 17:817–826
Shahidi F, Janitha PK, Wanasundara PD (1992) Phenolic antioxidants. Crit Rev Food Sci Nutr 32:67–103
Tapola NS, Lyyra ML, Karvonen HM, Uusitupa MI, Sarkkinen ES (2004) The effect of meat products enriched with plant sterols and minerals on serum lipids and blood pressure. Int J Food Sci Nutr 55(5):389–397
Yang CS, Landau JM (2000) Effects of tea consumption on nutrition and health. J Nutr 130 (10):2409–2412

5 Potential of Food Processing By-products as Dietary Fibers

Farhana Masood, Abdul Haque, Saghir Ahmad, and Abdul Malik

Abstract

The rapidly growing food processing industries in several countries of the world produce a large amount of by-products, such as husk, shells, pods, seeds, husks, stems, bran, stalks, and pulp waste that have less use and cause significant pollution. A huge potential for waste reduction and indirect income generation has been developed because of the possible use of by-products as a source of dietary fiber, functional or novel fiber for the production of diverse human foods. With the increasing concern on health that promotes functional foods, the need for natural bioactives has raised and leads to search of new sources. Studies has shown the high nutritional value of these by-products. It was also proposed that due to functional capability like gelling and water binding, they could be used as an ingredient for food. Several industrial by-products of food processing are high in dietary fiber sources and may be used directly or after some modifications for the manufacture of various foods, like bread, cakes, buns, noodles, cookies, yogurts, cheeses, beverages, milk, instant breakfasts, juices, ice tea, sports drinks, wine, fermented milk products and powdered drinks. This chapter gives insights about dietary fiber from food by-products; also, the chapter covers their classification, sources of origin, their potential uses, and functional properties.

Keywords

Agro industry by-products · Dietary fiber · Food processing · Polysaccharides · Viscosity

F. Masood (✉) · A. Haque · S. Ahmad
Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

A. Malik
Department of Agricultural Microbiology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_5

5.1 Introduction

The agri-food industry is a major global economy market. Agricultural crops and animal products are the primary raw materials used in these sectors. All food groups are used as raw materials for food processing, such as grains and pulses, fruits and vegetables, dairy and dairy products, oil seeds, meat and meat products. After the production of the desired commodity, the processing industries produce large quantities of by-products and waste and generally, most essential compounds remain in these by-products. Through further analysis they can be retrieved. The by-products, however, are specific to each material. The by-products of plant-based foods are bran, pills, pomace, hulls, fruit cover, kernels, leaves, seeds, cakes, etc. While food processing waste from animals are blood, skin, gut, milk, hair, hops, and so on. Bran by-products are high in DF, such as grain and fruit peel.

5.2 Dietary Fibers from Food Processing By-Products

Fruits and vegetables are essential dietary fiber sources. One-third of fruits and vegetables are covered by peel, skin, and pips. They were thrown away during the preparation and processing, producing a "waste." Such waste products are high in dietary fiber, polyphenols, tocopherol, carotenoids, and so on. Dietary fiber in such waste is one of the 333 most important nutrients. New methods are arising to employ these useful compounds from such waste in value-added products. Fiber has received a lot of interest recently as a potential pharmaceutical feed possible due to its ability to lower cholesterol, coronary heart disease, and diabetes and relieve constipation (Telrandhe et al. 2012). Because of their essential role in the conservation of human health, dietary fibers have been regarded as the seventh largest group of nutrients in humans after proteins, carbohydrates, fats, vitamins, minerals, and water.

5.3 Definition and Classification

The definition of dietary fiber has been updated many times since 1953 with the growth of understanding of the structure and functions of dietary fiber. In 1953, Hipsley (1953) coined the term "dietary fiber" and regarded it only as "a non-digestible constituent making up the plant cell wall." Since then, the concept has been generalized by many researchers (Trowell et al. 1985; Health and Welfare Canada 1985; IOM 2001; Spiller 2001; Sharma et al. 2012), but Trowell believed that it is resistant to the effects of human alimentary enzymes. Further he proposed that DF is not only composed of carbohydrates (cellulose, hemicellulose, pectin, etc.) but also have a non-carbohydrate-type (lignin).

Larrauri (1999) identified the "perfect fiber" with the following features:

- It must be highly concentrated in a small amount for maximum benefit.
- It must not have taste and negative effect on color, smell, or texture.
- It must have a balance between soluble and insoluble fiber with a suitable bioactive compound content.
- Addition of it shall not affect the product to which they are added, but shall have a long shelf life.
- It should have appealing image for the consumer.
- The predicted physiological effects should be included, and lastly
- It should have reasonable price.

Historically, for both their nutritional properties and their technological functions, fibers like wheat, maize, and rice were employed earlier in food production. Nevertheless, new fiber sources are found and used recently. One such source is the by-product fraction of various food processing types. In general, fruit and vegetable processing by-products (e.g., juices and beverages) are acquiring new and economic sources of a healthy functional component of attention (Ayala-Zavala et al. 2011). After the processing of products based on fruit and vegetables, these by-products may be referred to as residues. There are shells, pips, skins, roots, and pips in these remains. Presently the manufacturers typically dispose of these by-products at their expense through animal feed, landfill, or incineration. This can affect the environment negatively.

The Institute of Medicine (IOM) extended the definition's scope to isolated and synthesized carbohydrates in 2001 by dividing dietary fiber into three parts: Dietary Fiber, Functional Fiber, and Total Fibers (I.O.M. 2005). In 2009, Codex classified the concept into three sections: (1) natural edible carbohydrates, (2) those derived from food raw materials through physical, chemical, or enzymatic methods, and (3) those that are synthesized synthetically but have health benefits (Codex 2009). In 2012, the Bureau of Nutritional Sciences, Canada, reviewed the concept of dietary fiber and incorporated two forms of substances. First substances are carbohydrates of a polymerization degree of three or more, which naturally present in plant-based foods (e.g., vegetables, fruits, beans, legumes, cereals, and nuts) and which are not digested and absorbed by the small intestine, must be cooked or processed by conventional methods. The second class of substances are "accepted novel fibers." It has been stated that Novel fibers are "ingredients manufactured to be sources and are synthetically produced from natural sources, or which have been processed so as to modify the properties of the fiber contained therein." Examples of Novel Fibers are agricultural crop by-products and from raw plant materials, animal or microbial components, chemically altered ingredients, and synthetic products (B.N.S. 2010).

Total DF can be regarded to be the total sum of dietary fiber derived from natural plant sources (dietary fiber) and synthesized or processed fibers and then added to the food, i.e., functional/novel fiber. Both of these forms can be derived from microbes, plants, or animals. Such plant-based fibers can be classified into two forms: (1) carbohydrates and (2) non-carbohydrates (Fig. 5.1). The

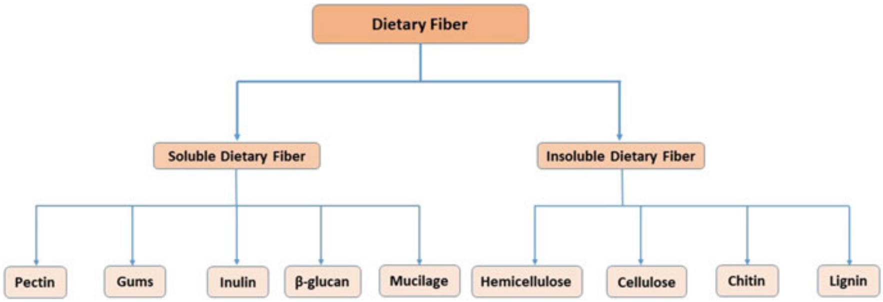


Fig. 5.1 Classification of dietary fiber

non-carbohydrate form is mostly lignin and the carbohydrate form can be cellulose or non-cellulose-based. Cellulose is a polysaccharide having a structural unit of glucose, whereas hemicelluloses include pentoses (xylose), hexoses, which are often mixed with a methyluronic acid. Cellulose is more polymerized in comparison to hemicelluloses. Cellulose is fibrous and less soluble in alkali, whereas hemicelluloses are non-fibrous and more soluble in alkali (Sharma et al. 2012). Dietary fiber is also classified for its solubility in water. Insoluble dietary fibers (hemicellulose, cellulose, and lignin) are lower in calories than soluble dietary fibers (pectin, glactomannans, β-glucans, oligosaccharides, fructans, some hemicelluloses, gums, mucous). Foods rich in insoluble fiber include flaxseed, breakfast cereals, whole grains, vegetables (carrots, celery, etc.), and cereal husks, and those that are high in soluble dietary fiber consist of vegetables (cabbage), legumes (lentils, beans), fruits (berries), oat bran, etc. (Wardlaw and Insel 1997; Sharma et al. 2012). Animal- or microbial-derived fibers can be yeast β-glucan, chitin, xanthan gum, etc.

5.4 Structure of Dietary Fiber

The fiber structure is complex in form. The plant fibers like carbohydrate, lignin, and other substances are primarily non-digestible, while animal-derived fibers are altered or synthetic non-digestible carbohydrate polymers. Non-digestible carbohydrate includes polysaccharides (cellulose, hemicellulose gums, ß-glucan, mucilage, inulin, pectin, resistant starch), oligosaccharides (fructo-oligosaccharides, oligofructose, polydextrose, galacto-oligosaccharides), and soybean oligosaccharides (stachyose and raffinose). The example of animal-based fiber is chitosan, obtained from chitin in crustaceans and squid pens exoskeletons; molecular structure of chitosan is like that of plant cellulose (Borderias et al. 2005). The main source of cellulose, lignin, and hemicellulose is cereals, while the main sources of pectin, gums, and mucilage are fruits and vegetables (Normand et al. 1987).

5.5 General Properties of Dietary Fiber

For each technical property, fibers as a food ingredient can provide physiological features.

5.5.1 Solubility

Dietary fiber is known as soluble or insoluble, depending on whether it forms a solution when combined with water (soluble) or not (insoluble). Soluble fiber includes pectins, gum, mucus, and certain hemicelluloses, while insoluble fraction includes cellulose, certain hemicelluloses, and lignin (Schneeman 1987; Davidson and McDonald 1998).

The solubility depends on the structure of the polysaccharides. The existence of a substitution unit like COOH or SO_2^{-4} increases the solubility. Temperature and ionic activity also affect the solubility (Fleury and Lahaye 1991; Manas and Bravo Saura-Calixto 1994). Soluble and insoluble nature of dietary fibers encompasses variations in their technical functionality and physiological properties (Jimenez-Escrig and Sanchez-Muniz 2000). Soluble fibers are distinguished by their ability to enhance viscosity and lessen glycemic response and plasma cholesterol (Roehrig 1988; Abdul-Hamid and Luan 2000). Insoluble fibers are distinguished by porosity, low density and ability to enhance stool volume and reduce intestinal transit (Roehrig 1988). The soluble fraction in food processing exhibits a greater ability of providing viscosity, the ability of forming gel formation and/or serve as emulsifiers, better texture and taste, and easily incorporated into processed foods and beverages compared to insoluble fiber. The major sources of soluble fiber are fruit by-products and marine algae and followed by vegetables, fruits, and cereals.

5.5.2 Properties of Hydration and Ability for Oil Binding

Through measuring water absorption, water-holding capacity and swelling, the hydration properties of fibers can be described. Water absorption refers to the kinetics of uptake of water measured by a Baumann Apparatus (Fleury and Lahaye 1991). It provides comprehensive information about the dietary fiber, in particular the pore volume of the substrate (Guillon and Champ 2000). Water-holding capacity (WHC) is the water retained by 1 g of dry fibers under certain conditions such as temperature, soaking time, velocity, and centrifugation period. Using the bed volume process, swelling (SW) can be calculated by swelling fibers in water all night in a volumetric cylinder (Kuniak and Marchessault 1972).

The hydration attributes of dietary fiber are linked to the chemical structure of the polysaccharides constituent and other parameters like particle size, ionic form, porosity, temperature, type of ions in solution, pH, ionic strength, and fiber loading. The capacity of fiber to store water is highly dependent on the dietary fiber source. DF from algae (e.g., *Laminaria digitata*) demonstrated higher preference for water and oil in comparison to those fibers obtained from fruit juice by-products. Lowest affinity is measured in cereal derivatives. The chemical properties of the fibers are correlated with these variations. Increase in temperature improves the properties of their hydration. A different ionic strength alters the extent of attraction of the fibers for water.

Fibers have, in addition to their hydrating properties, the ability to hold oil. Oil-holding capacity (OHC) is defined as "the quantity of oil retained by the fibers after mixing, incubation with oil and centrifugation." The water-holding capacity, swelling, and oil-holding capacity indicate some prospects of fibers used as components in foods: for example, high OHC dietary fibers tolerate stabilization of foods rich in fats and emulsions. High-WHC dietary fiber may be exploited as a functional ingredient to prevent syneresis and alter the texture and viscosity of certain processed foods (Grigelmo-Miguel and Martina-Belloso 1999a).

5.5.3 Viscosity

Water-soluble fibers are the key constituents that enhance the solution's viscosity. This shows that defatted rice bran has a low viscosity (~1.25 cps at 7% fiber in water) because it comprises of only 9% of soluble fibers. By increasing the fiber concentration, viscosity increases while it decreases with increase in temperature of dietary fiber solution.

5.5.4 Antioxidant Properties

Dietary fibers having high antioxidant activity can be used as constituents that help in the stabilization of fatty foods, accordingly improves their oxidation stability and prolongs the shelf life. Such fiber-rich foods possess several technical properties (water retention, water solubility, water swelling, viscosity, fat binding, and antioxidant properties) that justify their use in various food industries.

5.6 Health Benefits of Dietary Fibers

A vast array of studies and public concern regarding health benefits of dietary fiber has been evolved since the mid-1970s. Dietary fiber decreases diabetes, coronary heart disease, cholesterol, and precludes obesity as summarized in Table 5.1. Dietary fibers may be used by number of intestinal bacterial species as fermenting substrate, help to lessen pH rates in the intestine, limit the growth of saprophytic bacteria, minimize intestinal endotoxin accumulation, and prevent carcinogens from being generated (Thebaudin et al. 1997). Dietary fibers typically foster an adequate microenvironment and establish ideal conditions for intestinal flora. High-fiber foods reduce the risk of cancer by absorbing carcinogens. It is therefore recommended that dietary fiber be used to bind hydrophobic carcinogens. Fiber-

Table 5.1 Health benefits of dietary fibers

Functions	Benefits
Add bulk to diet	Reduce appetite
Hydration allows gel formation during digestion which traps carbohydrates and slows glucose absorption	Maintain blood sugar levels
Regulate blood pressure	Reduce risk of metabolic diseases and diabetes
Lower cholesterol	Reduce risk of heart diseases
Add bulk to fecal matter	Relieve constipation

rich foods improve digestion and slow down the uptake of glucose in the intestinal tract, which decreases diabetes. However, intake of fiber in higher amount affects the absorption of minerals like zinc, iron, magnesium, and calcium by the body. The short-term use of fiber can lead to bloating and abdominal cramps. Therefore, a gradual increase in the use of fiber in the diet protects against the harmful effects. WHO has suggested a total intake of 25 g of fiber per day (WHO/FAO 2003). The real amount of fiber, however, is between 14 and 29 g/day.

5.7 Sources of Dietary Fiber

To fulfill the nutrient and health needs, several food products are looked at and employed as a fiber source (Medhe et al. 2017). Food processing by-products have vast prospective to be likely used as a fiber source in different foods.

5.7.1 Fruits and Vegetables

Waste from the fruit processing industry is high in DF, and these by-products also contain bioactive compounds. Saura-Calixto first proposed the idea of antioxidant dietary fiber (ADF) with some requirements in 1988 so that 1 g of antioxidant dietary fiber must have a free-radical scavenging potential of at least 50 mg of vitamin E and more than 50% of the dietary fiber dry matter from the natural components of the material. Seeds and skin of wine waste are high in fiber and phenolics. Dietary fibers from grapes have greater effectiveness in lowering blood pressure and lipid profile than the oats fiber or psyllium because of the collective action of DF and antioxidants. Wine grape pomace (WGP) and ADF are used as antioxidants and antimicrobials to extend the shelf life of foods. For instance, ADF has great potential for incorporation into flour, producing high-fiber baked products, whereas ADF polyphenols may function as an antioxidant to improve the taste, color, and aroma of the food product. Tseng and Zhao (2013) described several examples of applications ADF. Mango peel powder employed for improving the macaroni's antioxidant properties (Ajila et al. 2007); usage of grape pomace along with sourdough for rye bread (Mildner-Szkudlarz et al. 2011; Tseng and Zhao 2013); apple pomace combined in wheat flour to increase the rheological properties of cakes (Sudha et al. 2007; Tseng and Zhao 2013) and grape seed flour used for muesli bars, pancakes, and noodles (Rosales Soto et al. 2011; Tseng and Zhao 2013).

Apple, orange, olives, and peach are mostly used to extract their juices. They all have a by-product from which various compounds with high added value can be obtained; among them, it is noteworthy that in the processing of functional foods the fiber fraction has ample prospects. There are also various types of vegetables like onion, artichoke, pepper, and asparagus which produce waste when processed, such as asparagus spears, which can make up to 40–50% of their fresh weight. They also possess soluble and insoluble fibers, with which new "functional foods" can be developed (Rodríguez et al. 1999). Cauliflowers possess high waste index and is a good source of protein (16.1%), cellulose (16%), and hemicellulose (8%). Among other vegetables, cauliflower is considered to be rich in DF and has both antioxidant and anticarcinogenic attributes. The main antioxidants in this plant family (Brassica) are phenolic compounds and vitamin C (Podsedek 2007).

Peel is generated as an important by-product of citrus fruits processing. Several additional food materials produce peel and pulp residues as a by-product, which is also a worthy source of dietary fiber. Citrus fibers, due to an improved balance between soluble and insoluble dietary fibers, are regarded as of higher quality than dietary fibers from cereals, and they also possess higher water-holding capacity and oil retention. Citrus dietary fibers also have bioactive compounds (flavonoids and vitamin C) with antioxidant properties, which can have a healthier effect than the dietary fiber itself. Lemons have the greatest antioxidant ability among all citrus fruits. Dietary fiber is not good nutritionally, but it is useful because of its functional and technological features. It is also reported that banana peel contains over 50% dietary fiber (Wachirasiri et al. 2009). The ratio of IDF/SDF is approximately 4.48:1–5.46:1 in the banana peel. Carrot remains comprises of a large fiber amount with cellulose constituting the major portion (51.6%), accompanied by lignin (32.2%), hemicellulose (12.3%), and pectin (3.88%) (Nawirska and Kwasniewska 2005), several research therefore focuses on recovery and use of fiber. It is reported that sweet potato peel contains about carbohydrates (79%), fat (12%), fiber (7%), ash (6%), and protein (3.06%). Dietary fibers were extracted from sweet potato residues through sieving process after starch isolation (Mei et al. 2010). The average yield and dietary fiber values were 9.97% and 75.19%, respectively. The average content in DF products was 31, 19, 16, 85, 15, 65, and 11, 38 g/100 g of dry matter, respectively, for cellulose, lignin, pectin, and hemicellulose, respectively.

5.7.2 Legumes

In three legume by-products, broad bean pod (*Vicia faba* L.), pea pod (*Pisum sativum* L.), and okara from soybean (*Glycine max* L.), Mateos-Aparicio et al. (2010) investigated the functional compounds. These by-products are rich in dietary fiber since it is their main component, that is, higher than 50% for the pea and okara pod and 40% for the broad bean pod. Okara is the major by-product of the preparation of soy milk and tofu. In addition, it has a more than 30% vegetable protein, and also high in fats like linoleic and oleic acids. Because of these features, such by-products may be employed in food enrichment. Both pod by-products have higher vegetable proteins level and also possess a significant amount of potassium, whereas pea pod has higher iron concentration. The soluble dietary fiber of these by-products has a major role in reducing cholesterol level and improving glucose tolerance in diabetics. While the insoluble dietary fiber is capable of increasing fecal bulk and decreasing gastrointestinal transit time and may be used to treat irritable bowel syndrome (Bosaeus 2004).

5.7.3 Cereals

Cereals are made up of several layers and have a greater amount of dietary fiber. The bran is composed of many micronutrients, phytochemical and fiber content. Particularly bran has higher DF content, and for rice bran, omega fatty acids, and comprises substantial amounts of starch, vitamins, protein, and dietary minerals. On an industrial level, the bran, especially wheat bran, is widely used for the processing of low-value products, such as compost and feed for livestock, and substantial quantities are disposed of in landfills. In order to develop nutritionally improved ingredients and products, dry fractionation methods allow bran to isolate and recover to effectively differentiate high- and low-value components. Wheat bran is being used to improve the fiber content of breads and breakfast cereals, particularly for those who want to increase their intake of dietary fiber to ease constipation. The dietary fiber content of cereal bran is generally based on its pentosan content, primarily as arabinoxylans and xylanes. The occurrence of phenolic acids, particularly ferulic acid, esterified in arabinoxylanes, provides this fraction ability for use as a source of polymers and oligosaccharides with antioxidant properties.

Wheat by-products have distinctive nutritional and functional features associated with quality of color and cooking and their DF content (Dexter et al. 1994a, b). Dietary fiber comprises of cellulose, hemicellulose, lignin, gums, pectin, and other polysaccharides and oligosaccharides related to plants. By-products from oat processing consist of bran or oat fiber, that seems as an appropriate fat substitute in ground beef and pork products because it possesses capacity of retaining water and emulating the concept of particle in ground beef in context to color and texture (Verma et al. 2011). The authors examined methods to improve low fat, low-salt, and high-fiber functional chicken nuggets. Verma et al. (2009) integrated several sources of fiber such as pea husk flour, apple pulp, gram hull flour, and bottle gourd, in various mixtures at a level of 10%.

5.7.4 Coffee, Tea, and Cocoa

Food industries respond to the food demand with greater safety and lower energy density, assigning more resources to the development of products enriched with dietary fibers, as with special mixtures of fiber, physiological and functional properties can be satisfied. The main waste product of the chocolate industry is cocoa husks, which can aid as a good source of dietary fiber for the low-calorie food category. Cocoa husk is a good source of dietary fiber and can be used as a supplement for other fiber sources or food products. Both the cocoa husk and the cocoa bean shell are ready source of dietary fiber, which is economical and covers about 40% (DF) of the TDF. The cocoa fiber has antioxidant and physicochemical properties, and used in making low-calorie and high-fiber foods, like chocolate cakes, chocolate cookies, and diabetic chocolate supplements, where the taste and color of cocoa fiber may be beneficial to these foods.

5.7.5 Oil Cakes

Oilseed cakes are high in fiber contents with high levels of non-starch polysaccharides (NSP) (Bharathidasan et al. 2008). Due to differences in the extraction methods of oil, their chemical composition varies. Oil cake, the main by-product of the oil production industry, comprises 80% of total dietary fiber (Valiente et al. 1995), while soy cake contains 3–5% fiber (Blasi et al. 2000). It was reported that the crude fiber content of canola, cottonseed, coconut, peanut, mustard, olive, palm kernel, sesame, soybean, and sunflower oil cakes was 9.7, 15.7, 10.8, 5.3, 3.5, 40.0, 37.0, 7.6, 5.1, and 13.2%, respectively (Brendon 1957; Maymone et al. 1961; Kuo 1967; Ewing 1997).

5.8 Application of Dietary Fiber in Different Food Industries

Generally, by including insoluble and soluble dietary fiber, several solid food products such as bread, cakes, noodles, pasta, and cookies can be prepared (Sudha et al. 2007; Nassar et al. 2008; Sharif et al. 2009). Nonetheless, for liquid products, that is, drinks, beverages, and milkshakes, soluble DF is desired because of its more dispersible nature and market demand (Bollinger 2001; Nelson 2001; Sendra et al. 2008). There are several examples of dietary fibers used in food products, like in beverages, baked goods, dairy, confectionery, frozen dairy, pasta, meat, and soups (Table 5.2). Dietary fibers applied in baking products improve freshness, shelf life, water retention ability, and dough smoothness. Also increase the nutritional level of food. In meat products, the addition of dietary fiber increases cooking performance, fat binding, water fixation, and texture (Cofrades et al. 2000).

Table 5.2 Application of dietary fibers from by-products in processed foods

Name	Dietary fiber source	Reference
Bread	Banana peels	Eshak (2016)
	Rice bran	Soares Júnior et al. (2009), Ameh et al. (2013)
	Rice bran (defatted)	Hu et al. (2009), Sairam et al. (2011)
	Soy hull	Anjum et al. (2006)
	Carrot pomace	Kumar and Kumar (2012)
Cakes	Mango peel	Noor Aziah et al. (2011)
	Passion fruit peel	de Oliveira et al. (2016)
	Orange peel	de Oliveira et al. (2016)
Cookies	Pigeon pea brokens, powder, and husk	Tiwari et al. (2011)
	Pomegranate peel	Ismail et al. (2014)
	Orange pulp	Larrea et al. (2005)
	Grape pomace	Mildner-Szkudlarz et al. (2013)
	Carrot pomace	Nagarajaiah and Prakash (2015)
	Tomato pomace	Bhat and Ahsan (2015)
Noodles	Banana peel	Choo and Aziz (2010)
	Wheat bran	Chen et al. (2011)
Jam	Peach dietary fibers	Grigelmo-Miguel and Martina-Belloso (1999b)
	Tomato pomace	Belović et al. (2017)
Ice creams	1.3% wheat, bamboo, inulin, apple fibers	Staffolo et al. 2004
	Pomegranate peel phenolics and pomegranate seed oil	Çam et al. (2013)
	Date fiber (3%), wheat bran (1.5%)	Hashim et al. (2009)
Beverages and drinks	Oat bran (4 g β-glucan)	Pentikainen et al. (2014)
	β-Glucan, cellulose beet root fiber	Nelson (2001)
Fermented milk	Citrus (orange and lemon) fiber	Sendra et al. (2008)
Meat products	Wheat bran in chicken patties	Talukdar and Sharma (2010)
	Peach dietary fiber in fermented sausages	Garcia et al. (2002)
Fish products	Soluble fibers such as carrageenans from algae, or guar and xanthan from seeds	Borderias et al. (2005)
	Grape pomace	Sanchez-Alonso et al. (2007)

1. The biochemical structure, cooking and texture properties of pasta are influenced by the addition of dietary fiber ingredients (Tudoric et al. 2002). The non-stick features of some food grain fibers aid in pasta extrusion. Noodles are an important part of the diet in Asian countries. Refined wheat flour (Zhang et al. 2010) is used for the production of noodles. Noodles with high fiber sold on markets are commonly produced by the addition of bran instead of soluble food fiber. The addition of gums makes the noodles firm and easier to rehydrate when cooked or soaked (Hou and Kruk 1979). A recent investigation revealed a good nutritional

value and a sensory acceptability of the noodles by adding banana flour rich in DF (Choo and Aziz 2010). Wheat bran is high in dietary fiber content and are used in preparation of noodles and steamed breads. Studies reveal that the quality of noodles is improved when 5–10% of dietary fiber is used(Chen et al. 2011). Carrot pomace have been used effectively to produce buns enriched with dietary fiber and vitamins (Kumar and Kumar 2012). The white grape pomace was tested as a potential source of DF and phenols, at 10, 20, and 30% in wheat biscuits preparation. The addition of 10% white grape pomace showed increase of 88% in total dietary fiber and provided a standard formulation (Mildner-Szkudlarz et al. 2013). Gorecka et al. (2010) used raspberry pomace at 25–50% levels for wheat cookies preparation and described that the SDF, IDF, and TDF of cookies enriched with raspberry fiber ranged from 0.46 to 1.75, 13.50 to 34.50, and 14.24 to 35.98%, respectively. The authors also measured NDF, ADF, cellulose, hemicelluloses, and lignin and showed a significant rise in content in comparison to control samples. Bose and Shams-Ud-Din (2010) suggested that cracker biscuits made by adding 5% processed husk be the best with regard to sensory value during their trials with chickpea peel.

2. The dietary fibers of citrus are added to a food product work satisfactorily as a food ingredient (Figuerola et al. 2005). Citrus DF is used for the following: (1) improving texture; (2) used as a bulking agent in low-sugar applications; (3) lessens use of fats by controlling humidity; (4) provides color; (5) acts as a natural antioxidant, also used in jams. Ocen and Xu (2013) showed high potential in the making of fiber-rich bread from frozen dough with a more suitable citrus taste from by-products of citrus.
3. Addition of dietary fibers from algae like carrageenan, guar, or xanthan in fishery products improves properties of water-binding activity, thickening and emulsion and gelation. Mainly, such fibers are integrated into chopped fish muscle or raw muscle, and also cause stiffness and elasticity in muscle protein. Grape pomace, having better antioxidant properties, applied to minced fish improves shelf life and taste and shields against lipid oxidation (Sanchez-Alonso et al. 2007).
4. A healthy diet requires the use of good-quality meat products. Meat is an essential source of high biological protein and offers vitamins, essential fatty acids, minerals, and several essential micronutrients. Generally, meat is poor in dietary fibers content. Therefore, efforts were made to add dietary fibers from different sources to surimi, sausages, meatballs, and other meat products with the goal of increasing the nutritional value. Adding dietary fibers in meat products such as sausages and hamburgers has no effect on their organoleptic features. The addition of dietary fiber to sausages from the wine processing has improved the nutritional quality (Mendes et al. 2014). Citrus fibers with bioactive compounds incorporated into meat products prevent lipid oxidation and decrease levels of nitrite. The use of grape pomace in chicken burgers enhances oxidative stability and prolongs shelf life.
5. In dairy products, dietary fibers are usually used, mainly inulin incorporated in dairy products. Fiber increases softness and texture, prevents melting, increases handling properties when temperatures vary during storage and maintains

crystallization or recrystallization controllers in frozen dairy products. It has been suggested that incorporating dietary fibers to yogurt improve texture, coherence, rheological properties, and product acceptability (Dello Staffolo et al. 2004; Sanz et al. 2008). Fibers decrease syneresis in yogurt and other fermented dairy products. Recent research has shown that the introduction of the Cupuassu pulp (*Theobroma grandiflorum*) into the goat's milk for yogurt increases consistency, texture, and high nutritional value (Costa et al. 2015). Today, application of orange fiber as a fat substitute in ice cream contributed to a 70% decline in fat, without affecting important modifications in product qualities like color, smell, and texture.

5.9 Conclusions

By-products of food processing are the main sources of dietary fibers, where some research is done and much more needs to be done. Recent research about dietary fibers obtained from the by-products of fruit and vegetables, cereals, or algae processing have expanded our understanding of their functional properties. These unwanted wastes rich in fiber can be reused as supplements that offer beneficial dietary fiber and bioactive compounds. They act as calorie-free fillers, improve water and oil retention, and enhance emulsion and oxidation stability. Such properties are beneficial and can be used in several foods including baked products, meat products, snacks, and diabetic drinks. Dietary fiber is well recognized as an essential ingredient in human diet. Health benefits of DF are as follows: they promote regulation and lower the risk of developing many life-threating diseases and conditions, like heart diseases, certain forms of cancer, type 2 diabetes, stroke, and obesity.

Acknowledgment F. M. is thankful to U.G.C., New Delhi, for financial assistance in the form of Postdoctoral Research Fellowship for Women.

References

Abdul-Hamid A, Luan YS (2000) Functional properties of dietary fiber prepared from defatted rice bran. Food Chem 68:15–19

Ajila CM, Naidu KA, Bhat SG, Prasada Rao UJS (2007) Bioactive compounds and antioxidant potential of mango peel extract. Food Chem 105:982–988

Ameh MO, Gernah DI, Igbabul BD (2013) Physico-chemical and sensory evaluation of wheat bread supplemented with stabilized undefatted rice bran. Food Nutr Sci 4:43–48

Anjum FM, Khan MI, Butt MS, Hussain S, Abrar M (2006) Functional properties of soy hulls supplemented wheat flour. Nutr Food Sci 36:82–89

Ayala-Zavala JF, Vega-Vega V, Rosas-Dominguez C, Palafox-Carlos H, Villa-Rodriguez JA et al (2011) Agro-industrial potential of exotic fruit by-products as a source of food additives. Food Res Int 44:1866–1874

Bharathidasan A, Chandrasekaran D, Natarajan A, Ravi R, Viswanathan K, Ezhilvalavan S (2008) Non-starch polysaccharides and phytate phosphorus content of commonly available poultry feed ingredients. Tamil Nadu J Vet Anim Sci 5:20–24

B.N.S. (2010) Proposed policy: definition and energy value for dietary fiber. Bureau of Nutritional Sciences, Food Directorate, Health Products and Food Branch, Health Canada. Accessed 5 March 2013. http://www.hcsc.gc.ca/fn-an/consult/fiber-fibers/consul-fiber-fibers-eng.php

Belović M, Torbica A, Pajić-Lijaković I, Mastilović J (2017) Development of low calorie jams with increased content of natural dietary fibre made from tomato pomace. Food Chem 237:1226–1233

Bhat MA, Ahsan H (2015) Physico-chemical characteristics of cookies prepared with tomato pomace powder. Food Proc Technol 7:1–4

Blasi DA, Drouillard J, Titgemeyer EC, Paisley SI, Brouk MJ (2000) Soybean hulls, composition and feeding value for beef and dairy cattle. Contribution No. 00-79-E. Kansas State University, Kansas

Bollinger H (2001) Functional drinks with dietary fiber. Fruit Proc 12:252–254

Borderias AJ, Sanchez-Alonso I, Perez-Mateos M (2005) New application of fibre in foods: addition to fishery products. Trends Food Sci Technol 16:458–465

Bosaeus I (2004) Fibre effects on intestinal functions (diarrhoea, constipation and irritable bowel syndrome). Clin Nutr Suppl 1(2):33–38

Bose D, Shams-Ud-Din M (2010) The effect of chickpea (*Cicer arietinim*) husk on the properties of cracker biscuits. J Bangladesh Agric Univ 8(1):147–152

Brendon RM (1957) Uganda Protectorate. Department of Veterinary Services and Animal Industry Occasional Bulletin No 1

Çam M, Erdogan F, Aslan D, Dinç M (2013) Enrichment of functional properties of ice cream with pomegranate by-products. J Food Sci 78:1543–1550

Chen JS, Fei MJ, Shi CL et al (2011) Effect of particle size and addition level of wheat bran on quality of dry white Chinese noodles. J Cereal Sci 53:217–224

Choo CL, Aziz NAA (2010) Effects of banana flour and β-glucan on the nutritional and sensory evaluation of noodles. Food Chem 119:34–40

Codex (2009) Codex Alimentarius Commission, ALINORM 09/32/26. Report of the 30th Session of the Codex Committee on Nutrition and Foods for Special Dietary Uses. Cape Town, South Africa, 3–7 November 2008

Cofrades S, Guerra MA, Carballo J, Fernández-Martín F, Jiménez-Colmenero F (2000) Plasma protein and soy fiber content effect on Bologna sausage properties as influenced by fat level. J Food Sci 65(2):281–287

Costa MP, Frasao BS, Silva ACO, Freitas MQ, Franco RM, Conte-Junior CA (2015) Cupuassu (*Theobroma grandiflorum*) pulp, probiotic, and prebiotic: influence on color, apparent viscosity, and texture of goat milk yogurts. J Dairy Sci 98:5995–6003

Davidson MH, McDonald A (1998) Fiber: forms and functions. Nutr Res 18:617–624

de Oliveira VR, Preto LT, Schmidt HO, Komeroski M, da Silva VL, Rios AO (2016) Physico-chemical and sensory evaluation of cakes made with passion fruit and orange residues. J Culinary Sci Technol 14:166–175

Dello Staffolo M, Bertola N, Martino M, Bevilacqua A (2004) Influence of dietary fiber addition on sensory and rheological properties of yogurt. Int Dairy J 14:263–268

Dexter JE, Martin DG, Sadaranganey GT, Michaelides J, Mathieson N et al (1994a) Preprocessing: effects on durum wheat milling and spaghetti-making quality. Cereal Chem 71(1):10–15

DexterJE, SymonsSJ, MartinDG (1994b) Enhancement of durum wheat quality by preprocessing and an evaluation of fluorescence imaging as a rapid technique for monitoring preprocessing efficiency. Assoc Oper Millers Bull 6415–6420

Eshak NS (2016) Sensory evaluation and nutritional value of balady flat bread supplemented with banana peels as a natural source of dietary fiber. Ann Agric Sci 61:229–235

Ewing WN (1997) The feeds directory. Context Publications, Leicestershire

Figuerola F, Hurtado ML, Estévez AM, Chiffelle I, Asenjo F (2005) Fiber concentrates from apple pomace and citrus peel as potential fiber sources for food enrichment. Food Chem 91:395–401
Fleury N, Lahaye M (1991) Chemical and physico-chemical characterisation of fibres from *Lamiaria digitata* (Kombu Breton): a physiological approach. J Sci Food Agric 55:389–400
Garcia ML, Dominguez R, Garlvez MD, Casas C, Selgas MD (2002) Utilization of cereal and fruit fibers in low-fat dry fermented sausage. Meat Sci 60:227–236
Gorecka D, Pacholek B, Dziedzic K, Gorecka M (2010) Raspberry pomace as a potential fiber source for cookies enrichment. Acta Sci Pol Technol Aliment 9(4):451–462
Grigelmo-Miguel N, Martina-Belloso (1999a) Comparison of dietary fibre from by-products of processing fruits and greens and from cereals. Lebensm Wiss Technol 32:503–508
Grigelmo-Miguel N, Martina-Belloso O (1999b) Influence of fruit dietary fiber addition on physical and sensorial properties of strawberry jams. J Food Eng 41:13–21
Guillon F, Champ M (2000) Structural and physical properties of dietary fiber, and consequence of processing on human physiology. Food Res Int 33:233–245
Hashim IB, Khalil AH, Afifi HS (2009) Quality characteristics and consumer acceptance of yogurt fortified with date fiber. J Dairy Sci 92(11):5403–5407
Health and Welfare Canada (1985) Report of the expert advisory committee on dietary fiber. Supply and Services Canada, Ottawa
Hipsley EH (1953) Dietary Fiber and pregnancy toxaemia. Br Med J 2:420–422
Hou G, Kruk M (1979) Asian noodle technology. Tech Bull 20:1–10
Hu G, Huang S, Cao S, Ma Z (2009) Effect of enrichment with hemicellulose from rice bran on chemical and functional properties of bread. Food Chem 115:839–842
I.O.M (2001) Institute of Medicine, Dietary reference intakes: proposed definition of dietary fiber. National Academy Press, Washington, DC, p 74
I.O.M (2005) Institute of Medicine, dietary reference intakes for energy, carbohydrate, Fiber, fat, fatty acids, cholesterol, protein, and amino acids. National Academy Press, Washington, DC
Ismail T, Akhtar S, Riaz M, Ismail A (2014) Effect of pomegranate peel supplementation on nutritional, organoleptic and stability properties of cookies. Int J Food Sci Nutr 65:661–666
Jimenez-Escrig A, Sanchez-Muniz FJ (2000) Dietary fibre from edible seaweeds: chemical structure, physicochemical properties and effects on cholesterol metabolism. Nutr Res 20:585–598
Kumar K, Kumar N (2012) Development of vitamin and dietary fiber enriched carrot pomace and wheat flour based buns. J Pure Appl Sci Technol 2(1):107–115
Kuniak L, Marchessault RH (1972) Study of the crosslinking reaction between epichlohydrin and starch. Die Starke 4:110–116
Kuo LH (1967) Animal feeding stuVs compositional data of feeds and concentrates (part 3). Malaysian Agric J 46:63–70
Larrea MA, Chang YK, Martinez-Bustos F (2005) Some functional properties of extruded orange pulp and its effect on the quality of cookies. LWT—Food Sci Technol 38:213–220
Larrauri JA (1999) New approaches in the preparation of high dietary fibre powders from fruit byproducts. Trends Food Sci Technol 10:3–8
Manas E, Bravo Saura-Calixto F (1994) Source of error in dietary fiber analysis. Food Chem 50:331–342
Mateos-Aparicio I, Redondo-Cuenca A, Villanueva-Suárez MJ, Zapata-Revilla MA, Tenorio-Sanz MD (2010) Pea pod, broad bean pod and okara, potential sources of functional compounds. LWT—Food Sci Technol 43(9):1467–1470
Maymone B, Battaglini A, Tiberio M (1961) Ricerche sul valore nutritive della sansa d'olive. Alimentazione Animale Alimentazione Animale 5:219–250
Medhe S, Anand M, Anal AK (2017) Dietary fibers, dietary peptides and dietary essential fatty acids from food processing by-products. In: Anal AK (ed) Food processing by-products and their utilization, vol 6. Wiley, Hoboken, pp 111–136
Mei X, Mu T-H, Jun-Juan H (2010) Composition and physicochemical properties of dietary fiber extracted from residues of 10 varieties of sweet potato by a sieving method. J Agric Food Chem 58:7305–7310

Mendes ACG, Rettore DM, Ramos ADLS, da Cunha SDFV, de Oliveira LC, Ramos EM (2014) Milano type salami elaborated with fibers of red wine byproducts. Cienc Rural 44:1291–1296

Mildner-Szkudlarz S, Bajerska J, Zawirska-Wojtasiak R, Gorecka D (2013) White grape pomace as a source of dietary fiber and polyphenols and its effect on physical and nutraceutical characteristics of wheat biscuits. J Sci Food Agric 93:389–395

Mildner-Szkudlarz S, Zawirska-Wojtasiak R, Szwengiel A, Pacynski M (2011) Use of grape by-product as a source of dietary fibre and phenolic compounds in sourdough mixed rye. Int J Food Sci Technol 46:1485–1493

Nagarajaiah SB, Prakash J (2015) Nutritional composition, acceptability, and shelf stability of carrot pomace-incorporated cookies with special reference to total and b-carotene retention. Cogent Food Agric 1:1–10

Nassar AG, AbdEl-Hamied AA, El-Naggar EA (2008) Effect of citrus by-products flour incorporation on chemical, rheological and organoleptic characteristics of biscuits. World J Agric Sci 4(5):612–616

Nawirska A, Kwasniewska M (2005) Dietary fibre fractions from fruit and vegetable processing waste. Food Chem 91:221–225

Nelson AL (2001) High-fiber ingredients, Eagan Press Handbook Series. Eagan Press, St. Paul

Noor Aziah AA, Lee Min W, Bhat R (2011) Nutritional and sensory quality evaluation of sponge cake prepared by incorporation of high dietary fiber containing mango (*Mangifera indica* var. Chokanan) pulp and peel flours. Int J Food Sci Nutr 62:559–567

Normand FL, Ory RL, Mod RR (1987) Binding of bile acids and trace minerals by soluble hemicelluloses of rice. Food Technol 41:86–99

Ocen D, Xu X (2013) Effect of citrus orange (*Citrus sinensis*) by-product dietary fiber preparations on the quality characteristics of frozen dough bread. Am J Food Technol 8:43–53

Pentikainen S, Karhunen L, Flander L, Katina K, Meynier A, Aymard P et al (2014) Enrichment of biscuits and juice with oat β-glucan enhances postprandial satiety. Appetite 75:150–156

Podsedek A (2007) Natural antioxidant capacity of brassica vegetables: a review. LWT—Food Sci Technol 40:1–11

Rodríguez R, Jiménez A, Guillén R, Heredia A, Fernández-Bolaños J (1999) Postharvest changes in 572 white asparagus during refrigerated storage. J Agric Food Chem 47:3551–3557

Roehrig KL (1988) The physiological effects of dietary fiber. Food Hydrocoll 2:1–18

Rosales Soto MU, Brown K, Ross CF (2011) Antioxidant activity and consumer acceptance of grape seed flour-containing food products. Int J Food Sci Technol 47:592–602

Sairam S, Gopala Krishna AG, Urooj A (2011) Physico-chemical characteristics of defatted rice bran and its utilization in a bakery product. J Food Sci Technol 48:478–483

Sanchez-Alonso I, Jimenez-Escrig A, Saura-Calixto F, Borderias AJ (2007) Effect of grape antioxidant dietary fibre on the prevention of lipid oxidation in minced fish: evaluation by different methodologies. Food Chem 101:372–378

Sanz T, Salvador A, Jimenez A, Fiszman SM (2008) Yogurt enrichment with functional asparagus fibre. Effect of fibre extraction method on rheological properties, colour, and sensory acceptance. Eur Food Res Technol 227:1515–1521

Schneeman BO (1987) Soluble and insoluble fibre-different physiological responses. Food Technol 41:81–82

Sendra E, Fayos P, Lario Y, Fernandez-Lopez JA, Sayas-Barbera E, Perez-Alvarez JA (2008) Incorporation of citrus fibers in fermented milk containing probiotic bacteria. Food Microbiol 25:13–21

Sharif MK, Masood SB, Faqir MA, Nawaz H (2009) Preparation of fiber and mineral enriched defatted rice bran supplemented cookies. Pak J Nutr 8(5):571–577

Sharma SK, Mangal M, Bansal S (2012) Dietary fibers in health foods. In: Gupta RK, Bansal S, Mangal M (eds) Health foods—recent trends and technological interventions. Biotech Books, New Delhi, pp 123–146

Soares Júnior MS, Bassinello PZ, Caliari M, Gebin PFC, Junqueira TD, Gomes VA et al (2009) Quality of breads with toasted rice bran. Cien E Tecnol De Alimentos 29:636–641

Spiller GA (2001) Definitions of dietary fiber. In: Gene AS (ed) CRC handbook of dietary Fiber in human nutrition, 3rd edn. CRC, Boca Raton, p 709

Staffolo MD, Bertola N, Martino M, Bevilacqua YA (2004) Influence of dietary fiber addition on sensory and rheological properties of yogurt. Int Dairy J 14(3):263–268

Sudha ML, Baskaran V, Leelavathi K (2007) Apple pomace as a source of dietary fiber and polyphenols and its effect on the rheological characteristics and cake making. Food Chem 104:686–692

Talukdar S, Sharma DP (2010) Development of dietary fiber rich chicken meat patties using wheat and oat bran. J Food Sci Technol 47(2):224–229

Telrandhe UB, Kurmi R, Uplanchiwar V, Mansoori MH, Raj VJ et al (2012) Nutraceuticals-phenomenal resource in modern medicine. Int J Univ Pharm Life Sci 2(1):179–195

Thebaudin JY, Lefebvre AC, Harrington M, Bourgeois CM (1997) Dietary fibres: nutritional and technological interest. Trends Food Sci Technol 8:41–48

Tiwari BK, Brennan CS, Jaganmohan R, Surabi A, Alagusundaram K (2011) Utilisation of pigeon pea (*Cajanus cajan* L) byproducts in biscuit manufacture. LWT—Food Sci Technol 44:1533–1537

Trowell H, Burkitt D, Heaton K (1985) Definitions of dietary Fiber and Fiber-depleted foods and disease. Academic, London, pp 21–30

Tseng A, Zhao Y (2013) Wine grape pomace as antioxidant dietary fiber for enhancing nutritional value and improving storability of yoghurt and salad dressing. Food Chem 138:356–365

Tudoric CM, Kuri V, Brennan CS (2002) Nutritional and physicochemical characteristics of dietary fiber enriched pasta. J Agric Food Chem 50(2):347–356

Valiente C, Arrigoni E, Esteban RM, Amado R (1995) Grape pom-ace as a potential food fiber. J Food Sci 60:818–820

Verma AK, Banerjee R, Sharma BD (2011) Quality of low fat chicken nuggets: effect of sodium chloride replacement and added chickpea (*Cicer arietinum* L.) hull flour. Asian Australas J Anim Sci 25(2):291–298

Verma AK, Sharma BD, Banerjee R (2009) Quality characteristics and storage stability of low fat functional chicken nuggets with salt substitute blend and high fiber ingredients. Fleisch Int 24 (6):54–57

Wachirasiri P, Julakarangka S, Wanlapa S (2009) The effects of banana peel preparations on the properties of banana peel dietary fiber concentrate. Songklanakarin J Sci Technol 31 (6):605–611

Wardlaw GM, Insel PM (1997) Perspectives in nutrition, 3rd edn. Mosby-Year Book, St. Louis, MO

WHO/FAO (2003) Diet, nutrition and the prevention of chronic diseases. Report of a joint WHO/ FAO expert consultation. WHO technical report series no. 916. World Health Organization, Geneva

Zhang W, Sun C, He F, Tian J (2010) Textural characteristics and sensory evaluation of cooked dry Chinese noodles based on wheat-sweet potato composite flour. Int J Food Prop 13:294–307

6 Encapsulation of Active Ingredients in Functional Foods: Current Trends and Perspectives

Ishfaq Hamid Dar, Shayeeb Ahmad Bhat, Arshied Manzoor, and Saghir Ahmad

Abstract

In recent times, there has been an increased demand for the development of functional foods which include whole, fortified, enriched, or enhanced foods that provide a potentially positive effect on health in addition to basic nutrition. There are different types of additives which are incorporated into the functional foods to improve the nutritional characteristics and organoleptic properties. These active ingredients like polyphenols, vitamins and probiotic microorganisms which have been proved to enhance human health are susceptible to environmental and processing conditions like temperature, light and pH. To enhance their stability and bioavailability, various strategies such as different drying methods, freeze concentration, various encapsulation techniques, osmotic dehydration and vacuum impregnation have been developed. In food systems, encapsulation techniques have found wide application in different fields. Its application will have a great impact on food systems which are primarily aimed at fortification and enrichment of nutrients and health-promoting active ingredients.

In this chapter, the different features of various active ingredients in functional foods will be discussed along with the different encapsulation techniques. The different encapsulation techniques will be further discussed along with their effectiveness and mechanisms. The different applications of encapsulated active ingredients will be presented along with the challenges and concerns in food systems.

Keywords

Encapsulation · Functional foods · Active ingredients

I. H. Dar (✉) · S. A. Bhat · A. Manzoor · S. Ahmad
Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_6

6.1 Introduction

During recent times, the notion of food has changed a lot. There has been an increased focus on the development of foods which serve additional functions besides providing basic nutrition. These foods, which are known as functional foods, contain certain active ingredients which provide specific health benefits in addition to improvement in nutritional and organoleptic properties. This concept of foods beyond basic nutrition accompanied by increased costs of healthcare has become more attractive in the present times. The functional foods have tremendous potential in improving the physical as well as mental well-being and in reducing the burden of different diseases prevalent due to lack of different nutritional components in food.

The improvement in the nutritional value of foods is generally done by supplementing the active ingredients in the food. This supplementation of different active ingredients has been used in the production of functional foods, e.g. orange juice fortified with calcium. The physiological effect of these active components has been proved by different studies, e.g. isoflavones help in lowering of cholesterol (Potter 1998). Besides providing health benefits, active ingredients such as probiotics and vitamin A are sensitive to processing and environmental conditions. This presents the challenge and research opportunity in the separation and incorporation of these components in functional foods. Encapsulation is among the different techniques for the preservation and stability of the active food components during processing, storage and also targeted delivery. The process of encapsulation coats the functional food ingredient with a food-grade material to isolate the components or core material from the external environment. This isolation protects the active component thereby enhancing its functionality. It effectively enhances the nutritional aspects of food and extends the shelf life. It also helps in masking off undesirable flavours and odours. There are many encapsulation techniques that can be used in the fabrication of microcapsules which include different mechanical and chemical methods. The functional properties of the microcapsules like morphology, encapsulation efficiency, stability and sustained release depend on the type of encapsulation method used and operating conditions (Morais et al. 2004).

Stability as a characteristic of encapsulation includes protection against oxidation, hygroscopic nature and thermal stability. For oxidation labile active components, double or hybrid encapsulates, have been developed for providing the necessary stability. Generally, polysaccharides are chosen as the coating material due to their cheap availability and other useful properties. They also enhance the solubility and bioavailability of the active components which are encapsulated. This feature of some polysaccharide as wall material, however, may cause diffusion of active substance due to large pore sizes (Zhang et al. 2016). So other compounds like $CaCl_2$ and transglutaminase may be added to the polysaccharide wall materials leading to the development of hybrid shells (Hosseini et al. 2014).

The sustained release of the active components from the microcapsules is essential so that they provide the desired effect after being digested and efficiently absorbed in the alimentary canal. There are different in vitro models for understanding the digestion process in the human gastrointestinal tract (Chen et al. 2016). For such studies, the different effects of physicochemical characteristics like temperature, pH and enzyme concentrations are analysed to model the in vivo digestion process. Food in the gastrointestinal tract is acted upon by a variety of enzymes. Inside the stomach, the gastric juice containing pepsin hydrolyses proteins to peptides under the condition of low pH (1.5–3.5). The pancreatic juice and bile catalyse degradation of carbohydrates, proteins and lipids and also raises the pH to 7. Bile salts play an important role in the emulsification of fats which increases the contact area for lipase action. The absorption takes place through the intestinal villi and microvilli which provide an increased surface area for the process. Thus, both physicochemical as well as morphological characteristics play an important role in the assimilation of active ingredients.

6.2 Active Ingredients

There is a large diversity of functional food components, also known as active ingredients, which have a beneficial effect on our health. These biomolecules which are present in functional foods as active components modulate one or more biochemical pathways in the body resulting in various health benefits. The health effect of functional components has been proved through a lot of research (Shibamoto et al. 2008). The functional foods are effectively used in the control and prevention of various diseases at various stages, thus making the line between food and medicines thinner (Pravst 2012). The different functional food ingredients largely include various phytochemicals that function as specific active chemicals inside the body providing health benefits (Murano 2003). This section presents the different active ingredients along with their encapsulation techniques and applications. The different classes of active ingredients in functional foods are shown in Fig. 6.1.

6.2.1 Active Polysaccharides

6.2.1.1 Dietary Fibre

The dietary fibres are an important part of a diet which are basically the structural components of the cell wall. They are composed of carbohydrate units held by β-linkages that human digestive enzymes cannot hydrolyse. So they consist of those carbohydrates which are not digested in the human gut. Dietary fibre is composed of cellulose, hemicellulose, pectins, β-glucans, resistant starch, non-digestible oligosaccharide (e.g. inulin), other synthetic carbohydrate compounds (e.g. methylcellulose), gums and mucilage, lignin and other minor components, e.g. phytic acid.

The fibrous structure of dietary fibres helps in trapping the harmful and undesirable toxins during the digestion process. β-glucan, which is present in cereals, has been reported to help in reducing the cholesterol levels (Izydorczyk and Dexter

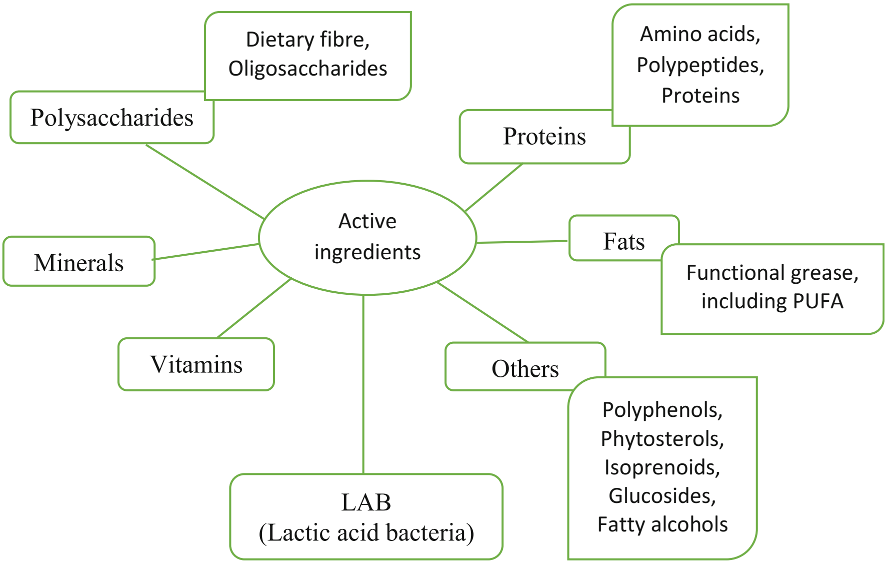


Fig. 6.1 Different classes of active ingredients in functional foods

2008). Insoluble dietary fibres add matter to the faecal bulk and also dilutes potential toxins and carcinogens in the digestive tract (Duss and Nyberg 2004; Ahmad et al. 2009, 2012; Havrlentová et al. 2011).

The benefits of these components of cellulose on the physiology are entirely dependent on the physicochemical properties which include solubility, binding ability, viscosity, fermentability and water-holding capacity. Based on the solubility, which largely influences the functionality of dietary fibre, there are two main components, i.e. soluble fibre—which dissolves in water—and insoluble fibre—which does not dissolve in water. The soluble fibres are readily fermented in the colon while as the insoluble fibres are inert to the digestion. The soluble fibres have a wide range of application in functional food development because of gelatinous and viscous properties. Some examples of these components include β-glucans, indigestible gums, inulins, chitooligosaccharides and lignins. These have been incorporated into the food formulations for the development of functional foods. According to several FDA claims, to accrue health benefits from foods higher quantities of fibres need to be added into the formulations.

The addition of fibres into the foods results in the increase in viscosity and makes them unpalatable. So encapsulation of dietary fibres comes into the picture to optimise the palatability without any undesirable changes in mouthfeel or flavour of final products. For example, encapsulation of chitooligosaccharides with polyacylglycerolmonostearate showed good encapsulation efficiency along with negligible changes in the sensory attributes of milk when added into it (Choi et al. 2006).

6.2.1.2 Oligosaccharides

There are different types of monosaccharides, and oligosaccharides are used as substitutes for sucrose in order to achieve the desired sweetness and provide other benefits in functional foods. These saccharides which are generally used in the functional food industry include various oligosaccharides comprising mainly disaccharides such as sucrose, maltose and lactose and monosaccharides such as glucose, fructose and galactose. The sweetness characteristic of these oligosaccharides is inversely related to the molecular weight. In almost all gut processes taking place in humans like digestion, absorption and other metabolic processes, beneficial effects of various oligosaccharides have been established (Mussatto and Mancilha 2007; Oku 1992; Torres et al. 2010). The substitution of sucrose by these oligosaccharides is quite advantageous. The ingestion of sucrose intimates a matrix in the presence of dental caries inducing bacteria *Streptococcus mutans*, resulting in tooth decay. It can be prevented by the use of sucrose substitutes which are not metabolised by *Streptococcus mutans* (Ooshima et al. 1983).

There are also marked differences in digestion and metabolism of these saccharides when compared to sucrose. Some oligosaccharides like neosugar (fructooligosaccharide) are non-digestible and not absorbed in the human intestines. They are fermented there by the bacteria into short-chain fatty acids (SCFA), thereby benefiting the host microorganisms (Tokunaga et al. 1989). It makes them useful as low glycaemic sweeteners. Others like the monosaccharide erythritol are low in energy density due to the fact that it is excreted through urine without any degradation (Noda and Oku 1992). This makes it beneficial in preventing obesity. In contrast, some saccharides like coupling sugar and palatinose are very digestible and raise blood glucose levels instantly. They are used as sweeteners alongside providing energy for those who require energy in higher amounts. In addition to these, there are many examples and areas of research on the saccharides that can be used as promising prebiotics also.

6.2.2 Proteins

Proteins play an important role in maintaining the health of humans. They are an important constituent of the structural and functional composition of cells. The proteins are digested by proteolytic enzymes into peptides and amino acids. There are 20 standard amino acids which are associated with the synthesis of different proteins and biomolecules. Out of these, eight essential amino acids have to be supplied by the diet for normal functioning of the body as they are not synthesised in the body. Besides being the primary supplier of amino acids, many proteins and peptides provide different health benefits. So they are recognised as active ingredients and used in the development of functional foods.

6.2.2.1 Amino Acids

The functions of amino acids in producing various therapeutic effects have been reported in different studies, for example the metabolism of methionine and its role in liver disease (Mato et al. 2008). The incorporation of non-essential amino acids into functional foods act as the building blocks of different bioactive components. In addition to this, several essential amino acids like valine and leucine which constitute a major proportion in muscle proteins play an important role in anti-fatigue and burn treatments.

The different amino acids including branched-chain amino acids (BCAAs) are poorly soluble in water which limits their bioavailability and have a bitter taste which results in their unacceptable palatability. These challenges present an opportunity for microencapsulation of these amino acids for supplementation. Microencapsulation of water-soluble amino acids done using phase separation process significantly affected the release behaviour (Mank et al. 1996). Several amino acids, especially branched-chain amino acids (BCAAs), have received much attention regarding their use in supplements and energy drinks. Microencapsulated BCAAs have been prepared using granulation and coated with gum arabic, polyglycerol fatty ester, etc. (Wu et al. 2013).

6.2.2.2 Peptides

There are different peptides which are recognised as bioactive compounds. Bioactive peptides such as casomorphins possess excellent bioactivity against hypertension (Pihlanto-Leppälä 2000). In the development of nutritional supplements for people who have problems in digesting intact proteins, in addition to active peptides, protein hydroxylates enriched with low molecular weight peptides play an important role. These are very beneficial in case of infants with lactose intolerance for cow milk. The bioactive peptides and protein hydroxylate products have been used in the development of different functional foods with health benefits. Some of these have found wide application in market products like soups, infant foods, whey proteins and fermented milk. This commercialisation of peptide products involves problems like perishable nature, less stability, little bioavailability and undesirable taste. So encapsulation offers an opportunity in overcoming these hindrances to some extent.

Encapsulation of casein hydroxylates using spray-drying with soybean protein as the coating material revealed a decrease in the bitterness as compared to free hydroxylates (Ortiz et al. 2009). Encapsulation of nisin using corn zein–glycerol blend by spray-drying demonstrated controlled and prolonged release of nisin (Xiao et al. 2011). Production of encapsulated protein hydroxylates has also shown little changes in the antioxidant activity (da Rosa Zavareze et al. 2014; Mosquera et al. 2014).

6.2.2.3 Proteins

Proteins are complex macromolecules with less stable structures. The secondary, tertiary or quaternary structures containing chemically reactive groups are sensitive to denaturation and aggregation on exposure to heat, light, oxygen or acidic/basic conditions. Proteins perform a variety of functions in the human body. They play an important role in enzymatic catalysis and synthesis in the body. They serve in the transport system in the body and are an indispensable part of contractile tissue, tendons, cartilage, etc. They are very vital in regulating different cellular and physiological activities. This makes them useful as active ingredients in the development of functional foods, thereby providing different nutritional and therapeutic benefits, for example β-galactosidase in the dairy industry, proteinase and lipase in the ripening process of cheese, etc.

People intolerant to lactose lack β-galactosidase, which hydrolyses lactose to glucose and galactose. This problem is overcome by enzymatic or chemical hydrolysis but produces a change in the flavour of the final product. If β-galactosidase is directly added to the milk, it makes it sweeter. So encapsulation of β-galactosidase is done in order to retain the characteristic original taste of milk and prevent its proteolysis in the stomach (Kim et al. 1999; Kwak et al. 2001). The ripening time of cheese is reduced by the use of encapsulated proteinase and lipase. The cheese ripening has been accelerated without any marked change in its quality. It also reduces the handling and capital cost as the ripening of cheese takes a long time (Kailasapathy and Lam 2005). Encapsulation of human therapeutic proteins in the development of formulations for sustained release has been analysed by many researchers, mostly by encapsulation of proteins using biodegradable microspheres made of poly-lactic-co-glycolic acid (PGLA) by emulsion method (Morita et al. 2000). This is mainly limited by the high cost of these materials.

6.2.3 Functional Grease, Including Polyunsaturated Fatty Acids

Fats are important constituents of diet for sustaining good health condition. Besides serving as stored energy reserves, fats, especially certain fatty acids, play an important role in various metabolic processes. Monounsaturated fatty acids are colourless, odourless and oxygen-labile like oleic acid and erucic acid. They are important components of vegetable oils like olive and rapeseed oil. Ricinoleic oil exhibits anti-inflammatory and analgesic activities in the topical application which makes it useful as a local anaesthetic. To prevent it from degrading due to oxidation and further its sustained release, ricinoleic oil has been encapsulated in chitosan liposomal microspheres (Azeem et al. 2015).

Polyunsaturated fatty acids like omega-3, on the other hand, consist of active components like α-linolenic acid, docosahexaenoic acid (DHA), and eicosapentaenoic acid (EPA) which play an important role in the reducing risk of cardiovascular disease besides improving mental and visual functions. Omega-3 fatty acid encapsulated and introduced into biscuits showed acceptable stability during storage and good sensory characteristics (Umesha et al. 2015). EPA and DHA are also present in fish oil with their characteristic fishy odour and oxygen sensitivity. Encapsulation of these compounds has shown good retention of oxidative characteristics and bioavailability (Chen et al. 2013). Other polyunsaturated fatty acids like omega-6, arachidonic acid, linoleic acid and conjugated linoleic acid (CLA) are also used as active ingredients in developing functional foods. CLA is an aqueous insoluble and oxygen-labile compound which possesses anticancer properties along with numerous other health benefits. Encapsulation of conjugated linoleic acid (CLA) with shell material as cyclodextrins has yielded enhancement in the oxidative stability (Kim et al. 2000).

6.2.4 Minerals

Minerals are among the very essential components of our diet. Based on the daily intake of minerals required by our body, they are classified as macro- and microelements. Calcium, potassium, sodium, copper, sulphur, chlorine and phosphorus are macro elements. The microelements include chromium, cobalt, fluorine, iodine, selenium, iron, manganese, zinc, copper and molybdenum. Deficiency of any of the macro or microelements leads to a variety of disorders and diseases. Calcium, phosphorus and magnesium are important for the healthy development of bones. Sodium and chlorine maintain the water and ion balances in the body. Zinc has an important role in blood clotting, while iron is necessary for RBCs for oxygen transport.

Nowadays mineral supplements are developed to provide for minerals like calcium, iron and magnesium to the people deficient in these minerals. The mineral fortification has become a new trend along with providing desirable protection from degradation and development of off-flavours during storage. Magnesium which has unpleasant sensory characteristics was encapsulated in sodium caseinate as w/o/w emulsion in order to provide a sustained release (Bonnet et al. 2010).

6.2.5 Vitamins and Carotenoids

Vitamins are either water-soluble (Vitamin B or C) or fat-soluble (Vitamin A, D, E and K, including carotenoids). They are naturally occurring biomolecules that play an important role in different metabolic processes taking place in our body. They occur in various chemical forms and carry out a lot of diverse functions. They can also be useful in the control and prevention of skin-related diseases, cancer, etc.

The bioavailability of fat-soluble vitamins A, D, E, K and carotenoids is limited due to their low solubility in water which impairs their absorption. To address such kind of issue with vitamin D_3, alpha-lactalbumin was used as a carrier for food enrichment (Delavari et al. 2015). On similar lines, vitamin B_9 having low aqueous solubility was entrapped in heteroprotein coacervates (Chapeau et al. 2017). Lycopene belonging to the class of carotenoids exhibits anticancer properties which was encapsulated using supercritical fluid extraction process (Blanch et al. 2007).

6.2.6 Other Phytochemicals

These include various compounds which are extracted from plants and provide different physiological benefits. They include polyphenols, phytosterols, alkaloids, isoprenes and cholines.

6.2.6.1 Polyphenols

These are a broad class of phytochemicals that include flavonoids, phenolic acids, tannins, coumarins and stilbenes. They generally exhibit excellent antioxidant properties along with anticancer and cardiovascular protective effects like resveratrol. Others like curcumin show antioxidant, anti-inflammatory, antiseptic and analgesic activity. Resveratrol having excellent antioxidant and anticancer properties is sensitive to both oxidation and light. It was successfully encapsulated to enhance the bioavailability (Sessa et al. 2014) and stability (Davidov-Pardo and McClements 2015). Curcumin having low bioavailability due to physical and chemical instability was encapsulated in peptide hydrogels resulting in the increased efficacy and bioavailability (Altunbas et al. 2011).

6.2.6.2 Phytosterols

Different phytosterols exhibit cholesterol-lowering properties, antioxidation, anti-inflammatory, anti-atherogenicity and anticancer activities. These include campesterol, sitosterol and stigmasterol. Stanols are the hydrogenated forms of sterols with similar physiological effects. Cholesterol is a representative type of zoosterols.

Phytosterols are sensitive to oxidation, especially due to the effect of increased temperature and light. The storage stability and retention were enhanced by encapsulation of phytosterol esters with milk proteins (Chen et al. 2013).

6.2.6.3 Isoprenoids

Isoprenoids are an important class of compounds which are composed of two or more isoprene units (five-carbon hydrocarbons) joined in a specific pattern. They play important functions in the physiology of plants as well as animals and function as pigments and aromatic substances. Monoterpenes are constituents of important volatile flavour compounds in essential oils. In order to extend the aroma in functional foods, their sustained release and protection against oxidation are enhanced by utilising the process of microencapsulation. Limonene was encapsulated to study the release profile and retention of aroma (Soottitantawat et al. 2005). Squalene is an excellent antioxidant but is sensitive to heat exposure and oxidation during storage and processing. It was encapsulated in lipid-based carriers as a treatment to Alopecia areata (Lin et al. 2013).

6.2.6.4 Glucosides

Glucosides are bioactive compounds which have a wide variety of therapeutic properties like antioxidant properties, antiseptic, diuretic and anti-inflammatory properties and skin whitening agents. In food applications, glucosides are used without encapsulation. Sinigrin and sinalbin which are present in pepper produce pungent taste. Encapsulation of glucosides is however used in pharmaceutical and cosmetic industries. For example, esculin which is a glucoside derivative is used in the treatment of nephrolithiasis. It is encapsulated in order to protect it from low pH in the stomach and provide its targeted delivery in the intestines (Tsirigotis-Maniecka et al. 2016).

6.2.6.5 Fatty Alcohols

Long-chain fatty acid alcohols are reported to reduce the cholesterol level in humans (Hargrove et al. 2004). Capsaicinoid which is found in chillies belongs to hydrophobic vanilloids having a pungent taste. It is used to treat arthritis and other diseases. Encapsulation of capsaicinoid was done to enhance the oral bioavailability of capsaicin (Zhu et al. 2015).

6.2.7 Lactic Acid Bacteria

Lactic acid bacteria (LAB) refers to a group of gram-positive bacteria which are non-pathogenic and produce lactic acid and are widely used in the fermentation process (Goldberg 2012). They consist of different species of *Lactobacillus, Streptococcus, Lactococcus, Leuconostoc* and *Pediococcus*. A new concept of probiotics also includes LAB alongside *Bifidobacterium* and *Enterococcus* species. According to FAO and WHO, probiotics refers to live strains of microorganisms which, when consumed in adequate amounts, confer health benefits to the host (FAO/WHO 2001). Probiotics provide a wide range of health benefits. They have been proven to be very effective in treating symptoms of lactose intolerance. They are useful in the treatment of diseases like diarrhoea and facilitate the ecological balance of intestinal microflora. The recognition of all these health benefits has made the development of functional foods containing probiotics very interesting field in the food industry.

In order to provide health benefits, there should be a minimum number of cfu/ml present in the probiotic food material. To ensure the optimum viability of cells after processing operations and storage, encapsulation methods have been devised such as freeze-drying, spray-drying and emulsification. The common coating materials used are alginates, starch, skim milk powders, etc. Encapsulation using freeze-drying with skim milk powder as encapsulant has been reported to prevent the membrane damage during the freeze-drying process (Castro et al. 1997) and have a protective effect on the suspended LAB (Sinha et al. 1974). The probiotic encapsulation through the process of spray-drying is necessary to reduce the high mortality rate during the drying process. Different coating materials have been tested like gum acacia which has improved the survival rate of LAB (Desmond et al. 2002). In addition to this, the process of spray-drying also increases the tolerance of microbial strains and ensures maximum viability in the intestinal environment (Huang et al. 2017).

6.3 Encapsulation Techniques

The process of encapsulation involves entrapment of one substance, i.e. the active component within another substance, i.e. wall material (Fang and Bhandari 2010). In the food industry, encapsulation is utilised to improve the delivery of different bioactive agents like vitamins, minerals, antioxidants and living cells like probiotics (deVos et al. 2010). With the advancement in modern-day technology, the incorporation of active ingredients in foods has become essentiality. These active components are highly susceptible to environmental and processing conditions. The action of the digestion process also diminishes their efficacy. These problems have been successfully overcome to some extent by encapsulation. Besides protecting against undesirable degradation, encapsulation aims towards stability, undesirable interactions, controlled release and targeted delivery of bioactive ingredients in functional foods. In addition to this, the encapsulation is also used to provide a barrier between bioactive core component and the environment, thereby allowing taste or aroma differentiation, masking the undesirable taste or smelling and increasing the bioavailability of active component (Lesmes and McClements 2009). There are several techniques for encapsulation of active components. Most of them are largely based on drying like spray-drying, fluid bed coating, spray chilling and spray cooling (Gibbs et al. 1999; Zuidam and Heinrich 2010).

6.3.1 Spray-Drying

Spray-drying is one of the most widely used encapsulation technique in the food industry. It is a very economical and flexible operation which produces particles of good quality (Zuidam and Heinrich 2010). This advantage of spray-drying encapsulation technique makes it desirable, concerning the sensorial and textural attributes of final food products. It is the most common commercial process for the preparation of dry flavourings. It has also been used to encapsulate vitamins, minerals aroma compounds, enzymes. There are also some disadvantages to this technique. Besides the complexity of the equipment, the drying conditions are not uniform. There is also no uniformity or control over particle size (Milanovic et al. 2010).

In this encapsulation process, modified starch, gum arabic, whey proteins or other wall materials are hydrated before being used. The material to be encapsulated and the carrier material are homogenised together usually in 1:4 ratio. This mixture is then fed through a nozzle which atomises the feed into the spray drier chamber. Hot air coming in contact with the atomised material evaporates the water. The dried encapsulated material is then collected through the bottom of the drier.

Modification of drying such as vacuum and freeze-drying provides flexibility in operating conditions for encapsulation of temperature-sensitive active components. Vacuum drying technique is cheap and faster, while freeze-drying requires high energy inputs and higher processing time (Zuidam and Shimoni 2010).

6.3.2 Extrusion Encapsulation

Extrusion encapsulation method involves dropping of an extruded combination of the active component and the aqueous solution of a polymer into a gelling bath. The extruder nozzle may be a modified pipette, syringe, atomising disc, etc. Electrostatic extrusion is very effective in the production of small-size particles (50 μm).

Co-extrusion involves the simultaneous extrusion of core component into the encapsulating substance. The encapsulating cylinder or head consists of concentric nozzles through which concentric feeds of coating and core material are extruded out of the device. As the head rotates, the core and the coating materials are coextruded through the concentric orifices (Schlameus 1995).

This technique is widely and exclusively used for encapsulation of flavours which are volatile and unstable, into glassy carbohydrate matrix. These carbohydrate matrices which act as encapsulating material are highly impermeable, which makes them useful for encapsulation of flavours. This characteristic of the process makes it advantageous for imparting very long shelf life to these flavour compounds, which are very prone to oxidation (Zasypkin and Porzio 2004). This process is also used for encapsulation of nutraceuticals. In operation of a lower temperature process, starch and glycerol along with water are fed into a twin-screw extruder maintained at 100 °C. The active ingredient to be encapsulated is injected in the end part of the barrel into the gelatinised mass which is cooled at about 50 °C. The extruded ropes are cut and dried (Quellet et al. 2001).

6.3.3 Emulsification Encapsulation

Emulsification technique is another frequently used method of encapsulation. It is used for water-soluble or lipophilic active components (Appelqvist et al. 2007). The emulsions can be water/oil or oil/water or water/oil/water double emulsion. The emulsification is followed by different drying methods such as spray-drying and freeze-drying to produce powders. These dried powdered encapsulated compounds are used in different formulations of functional foods (Zuidam and Shimoni 2010).

Generally, emulsions are made under the action of high shear in a homogeniser or any other high shear mixers. For encapsulation purpose, the emulsion should have fair stability before application and a consistent manner of release of the active component after application for desired delivery and action. The active ingredients that are soluble in water are encapsulated as water in oil emulsions or double emulsions. Oil in water emulsions affect the sensory characteristics due to change in the aqueous phase. Lipophilic or fat-soluble active ingredients like carotenoids, phytosterols, vitamin E, and aroma compounds are encapsulated as oil in water emulsions (Appelqvist et al. 2007).

6.3.4 Spray Chilling or Cooling

Spray chilling or cooling encapsulation technique is used to produce lipid-coated encapsulates. These two techniques differ in the melting point of lipids. Also, the encapsulating material is usually vegetable oil, in case of spray cooling and hydrogenated vegetable oil in spray chilling. This encapsulation technique in principle is similar to spray-drying, except that the core material to be encapsulated is mixed with the carrier material and atomised by cooled or chilled air as opposed to hot air in spray-drying (Risch 1995). The active agents to be encapsulated can be either in dried form or as an emulsion or can be dissolved in lipids. This technique of encapsulation can be operated both in batch and continuous modes and also produces high yield (Zuidam and Shimoni 2010; Gouin 2004). This encapsulation technique is less expensive and is used for heat-sensitive active components like vitamins, minerals, textural ingredients and flavours to improve heat stability.

Spray cooling is also called as matrix encapsulation because of the reason that the active components are present as aggregates buried into the fat matrix, and there is no true differentiation between core and shell as in case of true encapsulation. As a result of matrix encapsulation, some proportion of the active components lies on the surface, having direct exposure to the external environment, which causes quick release. Even though not being the perfect encapsulation, the bulk of the active ingredient remains encapsulated, thereby providing sufficient and desired applicability (Gouin 2004).

6.3.5 Fluidised Bed Coating

Fluidised bed coating as an encapsulation technique involves suspending the powder substance to be encapsulated by a stream of air at a specified temperature followed by spraying of coating material in atomised form. This technique can be operated in both continuous and batch modes. The coating material used can be cellulose, starch derivatives, proteins, fatty acids, waxes, emulsifiers (Dewettinck and Huyghebaert 1999). In this technique, the solid particles that are suspended in temperature and humidity-controlled chamber having a narrow range of particle sizes (50–500 μm) yielded optimum results (DeZarn 1995). The thickness of the coating on the particles depends on the time particles remain in the chamber. This technology is one of the efficient encapsulation technologies which applies shell material uniformly over the active components. This technique has the advantage of coating core materials with any wall material like fats, emulsifier, powders, cell extracts, proteins and polysaccharides. This feature makes it very versatile for stability and controlled release.

6.3.6 Coacervation

Coacervation is a microencapsulation technique which involves phase separation or precipitation of the colloidal phase or polymer-rich phase from an aqueous phase (Dziezak 1988). Depending on the number of polymer types present, coacervation can be simple, involving one type of polymer or complex involving two or more types of polymers. In simple coacervation a nonsolvent or more water-soluble polymer is used that competes for solubility, while as in complex coacervation the interaction between two oppositely charged polymers forms the capsules.

For encapsulation of active ingredients in functional foods, generally complex coacervation is used. In coacervation, the coating material in the form of polymeric solution is separated and coated uniformly over the suspended core particles followed by solidification (Pagington 1986). In complex coacervation, o/w emulsion of gelatin and gum arabic is generally used. This creates a polymeric emulsion of three immiscible phases among which the polymer-rich phase will get absorbed on the emulsion surface. This can be induced by changes in pH, temperature or dilution (Gouin 2004; Lemetter et al. 2009). The gum arabic can also be replaced by pectin, alginates or polyphosphates (Bakker et al. 1999; Gouin 2004) while as gelatin by whey proteins (Weinbreck et al. 2003). The different combinations of the polymers possess unique operating conditions with respect to temp, pH and charge density. There are also modified coacervation processes developed to get around the problems with commonly used gelatin–gum complex coacervation process when encapsulating heat-sensitive bioactive ingredients (Ijichi et al. 1997).

6.3.7 Liposome Entrapment

Liposomes refer to closed vesicles composed of lipid bilayers like phospholipids and cholesterol. They are formed when these lipids are dispersed in water followed by high shearing in a colloidal mill or any other fluidisation method. Liposomes are formed due to the hydrophobic and hydrophilic interactions between the lipids and water. In aqueous media, phospholipids orient themselves in such a way that the hydrophobic parts of subsequent layers get oriented towards hydrophobic parts of another layer. This results in the formation of lipid bilayer sheets. Due to the application of shear, this forms into spherical structures. The active agents to be encapsulated are entrapped within these compartments or attached to the membrane. The size of the liposomes varies from 25 nm to few microns. The aggregation of smaller vesicles into bigger ones is prevented by electrostatic repulsion or stearic stabilisation.

Liposomes are currently widely used in pharmaceutical applications for drug delivery (Torchilin et al. 2003). In the food industry, their use is limited and least explored. It is due to the physical and chemical instability during storage, less yield of encapsulation, higher costs, etc (Zuidam et al. 2003a, b). In the case of food applications, liposomes have been used in the ripening of cheese and other functions like the delivery of bioactive ingredients, thereby expanding the development of functional foods with improved quality and health benefits (Kirby et al. 1991).

6.3.8 Encapsulation Using Supercritical Carbon Dioxide ($scCO_2$)

The supercritical fluids are used for different purposes like extraction of bioactive compounds and chromatography due to solvating and transport properties (Tabernero et al. 2012; Reverchon and Adami 2006). Supercritical CO_2 is the supercritical fluid which has been mostly used in encapsulation processes in the food industry due to a lot of advantageous characteristics. It has low toxicity and has favourably low cost, non-inflammability, easy removal, etc. It is non-toxic and environmentally safe and leaves no residue, which makes it very suitable for food applications. The critical properties of temperature and pressure (304.2 K, 7.38 MPa) are easily achievable as compared to other fluids (Brunner 2005). These features make $scCO_2$ very much feasible for encapsulation purposes also. The changes in the different thermodynamic and kinetic factors can control the production process (Tabernero et al. 2012).

There are different techniques for encapsulation using supercritical fluids depending upon the role played by the supercritical fluid. These are Rapid Expansion of Supercritical Solution (RESS), Gas Antisolvent (GAS), Particles from Gas Saturated Solutions (PGSS), Carbon Dioxide-Assisted Nebulization, Supercritical Fluid Extraction of Emulsions (SFEE) technique, etc.

In Rapid Expansion of Supercritical Solution, the active ingredient and the coating material are homogenised into $scCO_2$. This mixture is then passed through a nozzle which results in the sudden drop in pressure. Due to this, the solvation power of $scCO_2$ decreases, the dissolved material precipitates and the coating material gets deposited over the active ingredient. The most important requirement for encapsulation through this process is that both the active ingredient and the coating or encapsulating material must have good solubility in the supercritical fluid (Zhu et al. 2010).

The process of Gas Antisolvent (GAS) involves the addition of supercritical fluid to the solution of active ingredient along with coating material in a primary solvent. The addition of supercritical fluid, which is termed as antisolvent, causes the volume expansion and supersaturation of the solution, thereby resulting in the precipitation of the particles of the active component. This happens due to the high diffusion rate of supercritical fluid ($scCO_2$) and decrease in solubility of solute (active ingredient plus encapsulant) in the primary solvent due to decrease in density (Cocero and Martin 2008). The solute here must have good solubility in liquid solvent, but should not dissolve in the supercritical fluid. The primary solvent must be miscible in the supercritical fluid (Francisco et al. 2014). The GAS technique operates in batch mode. It is a very advantageous technique due to its micronising ability and encapsulation of polar compounds. The trace residues of the primary solvent (organic) may remain in the particles obtained (Bakhbakhi et al. 2006; Cocero and Ferrero 2002).

The Particles from Gas Saturated Solutions (PGSS) technique involves mixing core substance and shell material in the supercritical fluid. This technique works on the principle of cooling due to the Joule-Thompson effect while depressurising of core and encapsulate in the supercritical fluid. During this process, the $scCO_2$ dissolved in substrate solution is depressurised with a nozzle that results in the formation of particles due to cooling effect by CO_2 release (Jung and Perrut 2001; Cocero et al. 2009; Bahrami and Ranjbarian 2007).

The encapsulation using supercritical carbon dioxide ($scCO_2$) has been commonly used for polymers and waxes. There are variations of the process for use in encapsulation of food components like PGSS-Drying, in which the $scCO_2$ acts as solute and the drying medium (Meterc et al. 2008). Examples of this process include the encapsulation of β-carotene in soy lecithin (de Paz et al. 2012).

6.3.9 Inclusion Complexation

This encapsulation technique involves molecular inclusion of active compound in a cavity-based material. The most common example is that of cyclodextrin, a cyclic derivative of starch in which six to eight glucose units are connected in the form of a ring. The inner cavity of this ring is lipophilic in which active component/molecule having an appropriate size can be entrapped into the cavity through hydrophobic interaction (Pagington 1986). The outer part of the ring is hydrophilic which can also be branched enzymatically to increase their solubility in water. Loading of cyclodextrins is achieved by the co-precipitation of the complex in the aqueous solution. β-cyclodextrin is the one that is most commonly used. The use is however limited by the regulations regarding novel food status. The internal cavity of the cyclodextrin molecular ring limits the inclusion to a few active compounds, e.g. flavours (Dziezak 1988). There are other examples of molecular inclusion encapsulation which include entrapment of lipids in amylose and use of ligand-binding proteins (De Wolf and Brett 2000).

6.4 Conclusion

The incorporation of active ingredients and the development of functional foods are largely challenged by the stability and targeted release of bioactive components. Encapsulation has offered effective methods to protect these active components in the functional foods along with providing numerous other benefits. These include prevention of loss of volatile aromatic compounds, protection against chemical deterioration and masking undesirable sensory attributes. Encapsulation is done through different methods which work in a specific set of conditions affecting the bioavailability of the active ingredients in functional foods. In order to get desired benefits, it is essential to develop encapsulation strategies which are suitable to the core materials. Moreover, the selection of shell material should be consistent with the functional properties that are expected which involve high nutritional value, food-grade nature or any specific characteristics like that of indigestible dietary fibres. There are certain instances where the encapsulated ingredients have been introduced into functional foods and commercialised. But it is largely in the research stage as the studies regarding the bioavailability and controlled release are scarcely investigated. The efficacy of functional foods can be greatly enhanced by the process of encapsulation. It has tremendous potential in improving the nutritional value of foods and also provides a variety of health benefits. Future research needs to focus on bridging the gap between the research and commercial stage. The encapsulation of bioactive components in functional foods and nutraceuticals offers vast opportunities in the field of the food industry as well as the pharmaceutical industry.

Acknowledgement The corresponding author is grateful to DST, New Delhi, for financial assistance in the form of INSPIRE Fellowship.

References

Ahmad A, Anjum FM, Zahoor T, Nawaz H, Din A (2009) Physicochemical and functional properties of barley β-glucan as affected by different extraction procedures. Int J Food Sci Technol 44(1):181–187

Ahmad A, Munir B, Abrar M, Bashir S, Adnan M, Tabassum T (2012) Perspective of β-glucan as functional ingredient for food industry. J Nutr Food Sci 2(2)

Altunbas A, Lee SJ, Rajasekaran SA, Schneider JP, Pochan DJ (2011) Encapsulation of curcumin in self-assembling peptide hydrogels as injectable drug delivery vehicles. Biomaterials 32 (25):5906–5914

Appelqvist LAM, Golding M, Vreeker R, Zuidam NJ (2007) Emulsion as delivery systems in foods. In: Lakkis JM (ed) Encapsulation and controlled release technologies in food systems. Blackwell, Ames, pp 41–48

Azeem RAE, Nada AA, Montaser AS (2015) Chitosan liposomal microspheres for ricinoleic acid encapsulation. J Appl Pharm Sci 5(11):055–062

Bahrami M, Ranjbarian S (2007) Production of micro-and nano-composite particles by supercritical carbon dioxide. J Supercrit Fluids 40(2):263–283

Bakhbakhi Y, Charpentier PA, Rohani S (2006) Experimental study of the GAS process for producing microparticles of beclomethasone-17, 21-dipropionate suitable for pulmonary delivery. Int J Pharm 309(1–2):71–80

Bakker E, Bühlmann P, Pretsch E (1999) Polymer membrane ion-selective electrodes–what are the limits? Electroanalysis 11(13):915–933

Blanch GP, del Castillo MLR, del Mar Caja M, Pérez-Méndez M, Sánchez-Cortés S (2007) Stabilization of all-trans-lycopene from tomato by encapsulation using cyclodextrins. Food Chem 105(4):1335–1341

Bonnet M, Cansell M, Placin F, Anton M, Leal-Calderon F (2010) Impact of sodium caseinate concentration and location on magnesium release from multiple W/O/W emulsions. Langmuir 26(12):9250–9260

Brunner G (2005) Supercritical fluids: technology and application to food processing. J Food Eng 67(1–2):21–33

Castro HP, Teixeira PM, Kirby R (1997) Evidence of membrane damage in Lactobacillus bulgaricus following freeze drying. J Appl Microbiol 82(1):87–94

Chapeau AL, Hamon P, Rousseau F, Croguennec T, Poncelet D, Bouhallab S (2017) Scale-up production of vitamin loaded heteroprotein coacervates and their protective property. J Food Eng 206:67–76

Chen Q, McGillivray D, Wen J, Zhong F, Quek SY (2013) Co-encapsulation of fish oil with phytosterol esters and limonene by milk proteins. J Food Eng 117(4):505–512

Chen L, Xu Y, Fan T, Liao Z, Wu P, Wu X, Chen XD (2016) Gastric emptying and morphology of a 'near real' in vitro human stomach model (RD-IV-HSM). J Food Eng 183:1–8

Choi HJ, Ahn J, Kim NC, Kwak HS (2006) The effects of microencapsulated chitooligosaccharide on physical and sensory properties of the milk. Asian Australas J Anim Sci 19(9):1347–1353

Cocero MJ, Ferrero S (2002) Crystallization of β-carotene by a GAS process in batch effect of operating conditions. J Supercrit Fluids 22(3):237–245

Cocero MJ, Martin A (2008) Precipitation processes with supercritical fluids: patents review. Rec Patents Eng 2(1):9–20

Cocero MJ, Martín Á, Mattea F, Varona S (2009) Encapsulation and co-precipitation processes with supercritical fluids: fundamentals and applications. J Supercrit Fluids 47(3):546–555

Davidov-Pardo G, McClements DJ (2015) Nutraceutical delivery systems: resveratrol encapsulation in grape seed oil nanoemulsions formed by spontaneous emulsification. Food Chem 167:205–212

Delavari B, Saboury AA, Atri MS, Ghasemi A, Bigdeli B, Khammari A, Goliaei B (2015) Alpha-lactalbumin: a new carrier for vitamin D3 food enrichment. Food Hydrocoll 45:124–131

Desmond C, Ross RP, O'Callaghan E, Fitzgerald G, Stanton C (2002) Improved survival of Lactobacillus paracasei NFBC 338 in spray-dried powders containing gum acacia. J Appl Microbiol 93(6):1003–1011

deVos P, Faas MM, Spasojevic M, Sikkema J (2010) Encapsulation for preservation of functionality and targeted delivery of bioactive food components. Int Dairy J 20(4):292–302

Dewettinck K, Huyghebaert A (1999) Fluidized bed coating in food technology. Trends Food Sci Technol 10(4–5):163–168

De Wolf FA, Brett GM (2000) Ligand-binding proteins: their potential for application in systems for controlled delivery and uptake of ligands. Pharmacol Rev 52(2):207–236

DeZarn TJ (1995) Food ingredients encapsulation. In: Risch SJ, Reineccius GA (eds) Encapsulation and controlled release of food ingredients. American Chemical Society, Washington, DC

Duss R, Nyberg L (2004) Oat soluble fibers (beta-glucans) as a source for healthy snack and breakfast foods. Cereal Foods World 49(6):320–325

Dziezak JD (1988) Microencapsulation and encapsulated ingredients. Food Technol 42(4):136–151

Fang Z, Bhandari B (2010) Encapsulation of polyphenols—a review. Trends Food Sci Technol 21 (10):510–523

FAO/WHO working group. (2001). Report of a joint FAO/WHO expert consultation on evaluation of health and nutritional properties of probiotics in food including powder milk with live lactic acid bacteria. Córdoba, Argentina (October 1–4, 2001)

Francisco RSM, Daiane FR, Daiane LB, Janaína FMB, Sandra RSF, Vladimir JO, Carlos AVB (2014) Encapsulation of astaxanthin from Haematococcus pluvialis in PHBV by means of SEDS technique using supercritical CO2. Ind Crop Prod 54(0):17–21

Gibbs BF, Kermasha S, Alli I, Mulligan CN (1999) Encapsulation in the food industry: a review. Int J Food Sci Nutr 50(3):213–224

Goldberg I (2012) Functional foods: Designer foods, pharma foods, nutraceuticals. Springer Science & Business Media, Dordrecht

Gouin S (2004) Microencapsulation: industrial appraisal of existing technologies and trends. Trends Food Sci Technol 15(7–8):330–347

Hargrove JL, Greenspan P, Hartle DK (2004) Nutritional significance and metabolism of very long chain fatty alcohols and acids from dietary waxes. Exp Biol Med 229(3):215–226

Havrlentová M, Petruláková Z, Burgárová A, Gago F, Hlinková A, Šturdík E (2011) β-Glucans and their significance for the preparation of functional foods—a review. Czech J Food Sci 29 (1):1–14

Hosseini SM, Hosseini H, Mohammadifar MA, German JB, Mortazavian AM, Mohammadi A et al (2014) Preparation and characterization of alginate and alginate-resistant starch microparticles containing nisin. Carbohydr Polym 103:573–580

Huang S, Méjean S, Rabah H, Dolivet A, Le Loir Y, Chen XD, Jan G, Jeantet R, Schuck P (2017) Double use of concentrated sweet whey for growth and spray drying of probiotics: towards maximal viability in pilot scale spray dryer. J Food Eng 196:11–17

Ijichi K, Yoshizawa H, Uemura Y, Hatate Y, Kawano Y (1997) Multi-layered gelatin/acacia microcapsules by complex coacervation method. J Chem Eng Jpn 30(5):793–798

Izydorczyk MS, Dexter JE (2008) Barley β-glucans and arabinoxylans: molecular structure, physicochemical properties, and uses in food products—a review. Food Res Int 41(9):850–868

Jung J, Perrut M (2001) Particle design using supercritical fluids: literature and patent survey. J Supercrit Fluids 20(3):179–219

Kailasapathy K, Lam SH (2005) Application of encapsulated enzymes to accelerate cheese ripening. Int Dairy J 15(6–9):929–939

Kim CK, Chung HS, Lee MK, Choi LN, Kim MH (1999) Development of dried liposomes containing β-galactosidase for the digestion of lactose in milk. Int J Pharm 183(2):185–193
Kim SJ, Park GB, Kang CB, Park SD, Jung MY, Kim JO, Ha YL (2000) Improvement of oxidative stability of conjugated linoleic acid (CLA) by microencapsulation in cyclodextrins. J Agric Food Chem 48(9):3922–3929
Kirby CJ, Whittle CJ, Rigby N, Coxon DT, Law BA (1991) Stabilization of ascorbic acid by microencapsulation in liposomes. Int J Food Sci Technol 26(5):437–449
Kwak HS, Ihm MR, Ahn J (2001) Microencapsulation of β-galactosidase with fatty acid esters. J Dairy Sci 84(7):1576–1582
Lemetter CYG, Meeuse FM, Zuidam NJ (2009) Control of the morphology and the size of complex coacervate microcapsules during scale-up. AICHE J 55(6):1487–1496
Lesmes U, McClements DJ (2009) Structure–function relationships to guide rational design and fabrication of particulate food delivery systems. Trends Food Sci Technol 20(10):448–457
Lin YK, Al-Suwayeh SA, Leu YL, Shen FM, Fang JY (2013) Squalene-containing nanostructured lipid carriers promote percutaneous absorption and hair follicle targeting of diphencyprone for treating alopecia areata. Pharm Res 30(2):435–446
Mank R, Gustafsson J, Horig J, Kochling W, Nerlich B (1996) U.S. Patent No. 5,503,851. U.S. Patent and Trademark Office, Washington, DC
Mato JM, Martínez-Chantar ML, Lu SC (2008) Methionine metabolism and liver disease. Annu Rev Nutr 28:273–293
Meterc D, Petermann M, Weidner E (2008) Drying of aqueous green tea extracts using a supercritical fluid spray process. J Supercrit Fluids 45(2):253–259
Milanovic J, Manojlovic V, Levic S, Rajic N, Nedovic V, Bugarski B (2010) Microencapsulation of flavors in carnauba wax. Sensors 10(1):901–912
Morais HA, Da Silva Barbosa CM, Delvivo FM, Mansur HS, Cristina de Oliveira M, Silvestre MPC (2004) Comparative study of microencapsulation of casein hydrolysates in lipospheres and liposomes. J Food Biochem 28(1):21–41
Morita T, Sakamura Y, Horikiri Y, Suzuki T, Yoshino H (2000) Protein encapsulation into biodegradable microspheres by a novel S/O/W emulsion method using poly (ethylene glycol) as a protein micronization adjuvant. J Control Release 69(3):435–444
Mosquera M, Giménez B, da Silva IM, Boelter JF, Montero P, Gómez-Guillén MC, Brandelli A (2014) Nanoencapsulation of an active peptidic fraction from sea bream scales collagen. Food Chem 156:144–150
Murano PS (2003) Understanding food science and technology (no. 04; TP370, M8.). Thomson/Wadsworth, Belmont
Mussatto SI, Mancilha IM (2007) Non-digestible oligosaccharides: a review. Carbohydr Polym 68 (3):587–597
Noda K, Oku T (1992) Metabolism and disposition of erythritol after oral administration to rats. J Nutr 122(6):1266–1272
Oku T (1992) Dietary fiber and new sugars. Nat Res Hum Health:159–170
Ooshima TAKASHI, Izumitani A, Sobue S, Okahashi N, Hamada S (1983) Non-cariogenicity of the disaccharide palatinose in experimental dental caries of rats. Infect Immun 39(1):43–49
Ortiz SEM, Mauri A, Monterrey-Quintero ES, Trindade MA, Santana AS, Favaro-Trindade CS (2009) Production and properties of casein hydrolysate microencapsulated by spray drying with soybean protein isolate. LWT—Food Science and Technology 42(5):919–923
Pagington JS (1986) Beta-cyclodextrin and its uses in the flavour industry. In: Birch GG, Lindley MG (eds) Developments in food flavours. Elsevier, Amsterdam
de Paz E, Martín Á, Cocero MJ (2012) Formulation of β-carotene with soybean lecithin by PGSS (particles from gas saturated solutions)-drying. J Supercrit Fluids 72:125–133
Pihlanto-Leppälä A (2000) Bioactive peptides derived from bovine whey proteins: opioid and ace-inhibitory peptides. Trends Food Sci Technol 11(9–10):347–356
Potter SM (1998) Soy protein and cardiovascular disease: the impact of bioactive components in soy. Nutr Rev 56(8):231–235

Pravst I (2012) Functional foods in Europe: a focus on health claims. In: Valdez B (ed) Scientific, health and social aspects of the food industry. In Tech, Rijeka, pp 165–208

Quellet, C., Taschi, M. & Ubbink, J.B. (2001). Composite material—encapsulation of sensitive components into a matrix to obtain discrete shelf-stable particles. US pat 0008635.PCT WO 2001025414 A1

Reverchon E, Adami R (2006) Nanomaterials and supercritical fluids. J Supercrit Fluids 37(1):1–22

Risch SJ (1995) Encapsulation: overview of uses and techniques. In: Risch SJ, Reineccius GA (eds) Encapsulation and controlled release of food ingredients, vol 590. American Chemical Society, Washington, DC, pp 2–7

da Rosa Zavareze E, Telles AC, El Halal SLM, da Rocha M, Colussi R, de Assis LM et al (2014) Production and characterization of encapsulated antioxidative protein hydrolysates from Whitemouth croaker (Micropogonias furnieri) muscle and byproduct. LWT—Food Sci Technol 59(2):841–848

Schlameus W (1995) Centrifugal extrusion encapsulation. In: Risch SJ, Reineccius GA (eds) Encapsulation and controlled release of food ingredients, vol 590. American Chemical Society, Washington, DC, pp 96–103

Sessa M, Balestrieri ML, Ferrari G, Servillo L, Castaldo D, D'Onofrio N, Donsì F, Tsao R (2014) Bioavailability of encapsulated resveratrol into nanoemulsion-based delivery systems. Food Chem 147:42–50

Shibamoto T, Kanazawa K, Shahidi F, Ho C-T (eds) (2008) Functional foods and health, ACS Symposium Series, vol 993. American Chemical Society, Washington, DC, pp 1–6

Sinha RN, Dudani AT, Ranganathan B (1974) Protective effect of fortified skim milk as suspending medium for freeze drying of different lactic acid bacteria. J Food Sci 39(3):641–642

Soottitantawat A, Bigeard F, Yoshii H, Furuta T, Ohkawara M, Linko P (2005) Influence of emulsion and powder size on the stability of encapsulated D-limonene by spray drying. Innov Food Sci Emerg Technol 6(1):107–114

Tabernero A, del Valle EMM, Galán MA (2012) Supercritical fluids for pharmaceutical particle engineering: methods, basic fundamentals and modelling. Chem Eng Process Process Intensif 60:9–25

Tokunaga T, Oku T, Hosoya N (1989) Utilization and excretion of a new sweetener, fructooligosaccharide (Neosugar), in rats. J Nutr 119(4):553–559

Torchilin VP, Weissig V, Martin FJ, Heath TD, New RRC (2003) Surface modification of liposomes. In: Liposomes: A practical approach. Oxford University Press, Oxford, pp 193–229

Torres DP, Gonçalves MDPF, Teixeira JA, Rodrigues LR (2010) Galacto-oligosaccharides: production, properties, applications, and significance as prebiotics. Compr Rev Food Sci Food Saf 9 (5):438–454

Tsirigotis-Maniecka M, Gancarz R, Wilk KA (2016) Preparation and characterization of sodium alginate/chitosan microparticles containing esculin. Colloids Surf A Physicochem Eng Asp 510:22–32

Umesha SS, Manohar RS, Indiramma AR, Akshitha S, Naidu KA (2015) Enrichment of biscuits with microencapsulated omega-3 fatty acid (alpha-linolenic acid) rich garden cress (Lepidium sativum) seed oil: physical, sensory and storage quality characteristics of biscuits. LWT—Food Science and Technology 62(1):654–661

Weinbreck F, De Vries R, Schrooyen P, De Kruif CG (2003) Complex coacervation of whey proteins and gum arabic. Biomacromolecules 4(2):293–303

Wu W, Chen J, Zhang Y (2013) Microencapsulated amino acid composition and the method of manufacturing the microencapsulated amino acid composition, U.S. Patent Application No. 14/052,312. U.S. Patent and Trademark Office, Washington, DC

Xiao D, Davidson PM, Zhong Q (2011) Spray-dried zein capsules with coencapsulated nisin and thymol as antimicrobial delivery system for enhanced antilisterial properties. J Agric Food Chem 59(13):7393–7404

Zasypkin D, Porzio M (2004) Glass encapsulation of flavours with chemically modified starch blends. J Microencapsul 21(4):385–397

Zhang Z, Zhang R, Chen L, McClements DJ (2016) Encapsulation of lactase (β-galactosidase) into κ-carrageenan-based hydrogel beads: impact of environmental conditions on enzyme activity. Food Chem 200:69–75

Zhu L, Lan H, He B, Hong W, Li J (2010) Encapsulation of menthol in beeswax by a supercritical fluid technique. Int J Chem Eng. https://doi.org/10.1155/2010/608680

Zhu Y, Wang M, Zhang J, Peng W, Firempong CK, Deng W, Wang Q, Wang S, Shi F, Yu J, Xu X (2015) Improved oral bioavailability of capsaicin via liposomal nanoformulation: preparation, in vitro drug release and pharmacokinetics in rats. Arch Pharm Res 38(4):512–521

Zuidam NJ, Heinrich E (2010) Encapsulation of aroma. In: Zuidam NJ, Nedovic VA (eds) Encapsulation technologies for active food ingredients and food processing. Springer, New York, pp 127–160

Zuidam NJ, Shimoni E (2010) Overview of microencapsulates for use in food products or processes and methods to make them. In: Zuidam NJ, Nedovic VA (eds) Encapsulation technologies for active food ingredients and food processing. Springer, New York, pp 3–29

Zuidam NJ, De Vrueh R, Crommelin DJA (2003a) Characterization of liposomes. In: Liposomes: A practical approach. Oxford University Press, Oxford, pp 31–78

Zuidam NJ, Van Winden E, De Vrueh R, Crommelin DJA (2003b) Stability, storage, and sterilization of liposomes. In: Liposomes: A practical approach. Oxford University Press, Oxford, pp 149–165

Cereals as Functional Ingredients in Meat and Meat Products

7

Shayeeb Ahmad Bhat, Arshied Manzoor, Ishfaq Hamid Dar, and Saghir Ahmad

Abstract

With the increasing awareness among consumer regarding food they eat, researchers shifted their focus from conventional foods to functional foods. Reasons being the studies showing various health risks associated with various food items like meat and poultry. Meat products have suffered the most due to their negative impact on health. Despite being one of the most nutritious food items in terms of proteins with high biological value, mineral content, vitamins, etc., it is not appreciated quite often as there are evidences relating meat consumption especially red meat to colorectal cancers, type 2 diabetes, cardiovascular diseases, hypertension, etc. With all these apprehensions in mind, researchers are looking for other sources which could be incorporated in meat products to reduce these health issues. Cereals happen to play a promising role in addressing all these concerns as they are rich in various phytochemicals, dietary fiber, etc. which have positive impact on health and physiological characteristics of meat. Non-starch polysaccharides (NSP) such as β glucan, arabinoxylans, arabinogalactans, and phenolics of cereals have acquired much importance because of their potential to act as prebiotics, antioxidants, immunomodulators, anticancer agents, cardio-protectors and anti-diabetic. Cereal germ is an important ingredient for the development of functional meat products because of its rich nutrient content and antioxidant property. They also contain minerals like Mg, K, Ca, and P, and they can also help in maintaining blood pressure. The aim of this chapter is to highlight the various components of cereals (oats, barley, wheat, rye, etc.) which can be used in meat products to improve their quality.

S. A. Bhat (✉) · A. Manzoor · I. H. Dar · S. Ahmad
Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_7

Keywords

Functional foods · Cereals · β glucan · Dietary fiber · NSP

7.1 Introduction

With the increase in demand for healthier foods by consumers, food sector needs to redirect its new product development to the area of functional food development by incorporating various functional ingredients in food items like meat products, baby foods, and bakery (Charalampopoulos et al. 2019). Meat as defined by various authors is the flesh of an animal like cattle, poultry, and fish and is the most nutritious food in terms of protein quality as it contains proteins with high biological value. It contains all the essential amino acids or indispensable amino acids (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine) which are not synthesized by the human body and has to be supplied to the human body through the food. Especially red meat is an important source of vitamins (vitamin B-6) and minerals, in particular zinc and iron (Boyle 1994). Despite its nutritional properties, consumption of meat and meat products has adverse effect on the human health, and strongest evidence of its adverse effect on health is increased risk of developing colorectal cancer with high consumption of processed meat (Godfray et al. 2018). Processed meat has been categorized as carcinogenic to human because of its links to colorectal cancer, whereas red meat is categorized as probably carcinogenic to humans by the World Health Organization's International Agency for Research on Cancer (IARC) (Bouvard et al. 2015). However, it is not yet clear how high intake of processed meat increases the risk of developing colorectal cancer. Elements like polycyclic aromatic hydrocarbons (PAH) and N-nitroso compounds formed during cooking of processed meat products might be the carcinogenic agents in meat (Bouvard et al. 2015). Some researchers argue since meat contains saturated fatty acids and high quantity of salts which increases the low density lipoprotein (LDL) cholesterol and blood pressure leading to various cardiovascular diseases. Trimethylamine N-oxide generated from L-carnitine in meat may also be involved in the development of adverse health effects in humans (Wolk 2017; Wang et al. 2011). High meat consumption is also associated with the risk of developing many other chronic diseases like obesity and diabetes (type 2 diabetes). These health hazards associated with meat have forced consumers to look for health-oriented functional meat products.

Functional meat products are developed by incorporating health-benefiting ingredients like dietary fiber, antioxidants, proteins, and polyunsaturated fatty acids. Meat is devoid of fiber, and meat products incorporated with ingredients containing dietary fiber are considered as better substitutes due to their functional and health effects (Hur et al. 2009). Cereal grains like oats, barley, wheat, quinoa, and psyllium are good sources of dietary fiber which helps to improve or maintain the gut health and are also good sources of other phytochemicals (β glucans, lignans, phytic acid, terpenes, ferulic acid, etc.). They contains good amount of vitamins like

Vitamin E, B, B_2, and B_3, and minerals (potassium, phosphorous, magnesium, calcium, etc.) because of the presence of all these components cereals could be used as potential ingredients in developing meat products with better quality and shelf life.

7.2 Status of Meat Production Industry in India

Livestock sector is an important sector of Indian economy as it provides livelihood to most of the population in rural areas. India has huge resource of livestock and poultry which play an important role in ameliorating the social and economic status of farmers and weaker sections of society in rural areas (Kumar et al. 2018). It provides employment to about 8.8% of the population in rural areas and also contributes 4.11% of gross domestic product (GDP) and 25.6% of total agriculture GDP. Livestock population in India is highest in the world and accounts 11.54% of total in the world. India is also the largest exporter of buffalo meat in the world. Total livestock population excluding poultry in India was 512.05 million out of which buffalo population was 108.70 million (Singh 2018) and currently it stands at 535.78 million as per 20th livestock census (Table 7.1). Meat production has increased appreciably to 7.0 million tonnes in 2015–2016 from 5.9 million tons in the 2012–2013. Annually meat production in India grows at a rate of 4%. Buffalo meat, poultry and marine processing rate is 21%, 6% and 8%, respectively. The livestock in India contributes considerably in the production of leather, wool, etc. while as leather is the most valuable product having very high export potential. India produced about 41.5 million kilograms of wool per annum during 2017–2018 (annual report DADF 2018–2019).

India's total import and export of livestock and livestock products in 2016–17 was Rs 257,742,166 and Rs 185,233,966, respectively (Singh 2018). India has taken lead in the export of buffalo meat and dethroned Brazil which was its largest exporter of buffalo meat as per United States Department of Agriculture (USDA) and exports meat to around 65 countries in the world.

Table 7.1 Livestock population in India

Census year	Buffalo	Sheep	Goat	Pigs	Poultry	Cattle
Livestock census 2003 (millions)	97.90	61.50	124.40	13.50	489.00	185.20
Livestock census 2007 (millions)	105.30	71.60	140.5	11.10	648.80	199.10
Livestock census 2012 (millions)	108.70	65.07	135.20	10.30	729.20	199.90
Livestock census 2017 (millions)	109.85	74.26	148.88	9.06	851.81	192.49

Sources: Annual report 2017–18, Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture and Farmers Welfare, Government of India

7.2.1 Constraints to Meat Industry

Despite leading the world in livestock population, India has not fully been able to increase the meat processing industry as hardly as 1% of total meat produced in India is subjected to commercial processing. There are various factors responsible for this limited growth of meat industry as discussed below.

- Feed and fodder shortage: The livestock is mainly reared by people in rural areas, and they depend entirely on common grazing lands. Area under grazing lands has been decreasing quantitatively as well qualitatively due to increasing livestock population and ineffective policies of government.
- Diseases: Diseases in cattle like foot and mouth, and black quarter are common in India causing death of considerable population of animals leading to decrease in meat production.
- Unhygienic conditions: Due to unhygienic conditions in slaughter houses, transportation of meat from Indian meat industry is below par with the international standards, thereby hampering meat export from India.
- Sociocultural factors also affect the meat consumption as various sections of society do not eat meat products, e.g. Muslims do not eat pork and Hindus do not eat beef because of religious beliefs.
- Poor infrastructure regarding cold chain storage contributes to the decrease in meat production because of limited shelf life of meat.

7.3 Cereals in Meat Products

Regarding meat products, recent studies have revealed that frequent consumption of meat products leads to prevalence of several diseases like coronary heart disease, diabetes, cancer, and obesity (Boada et al. 2016). Due to growing evidence on detrimental effects of consumption of meat products on human health, international and national nutrition program and policies have been designed to formulate the meat products by incorporating bioactive components from various sources like cereals, fruits, and vegetables to satisfy the need of health-conscious consumers. World Health Organization has recommended that fat in the meat products should be limited to 15–30% of calories in the diet in which saturated fat should not be more than 10% (Grasso et al. 2014). Research has shown a relationship between the diets rich in energy and various chronic diseases, thereby recommending diet high in dietary fiber level (Kaeferstein and Clugston 1995; Johnson and Southgate 1994). Cereals find a suitable role in the development of meat products with health benefits as they contain bioactive components like fiber, phytochemicals, and phytostereols. Cereal polysaccharides can improve the technological and nutritional qualities of meat products as they can serve as in the form of prebiotics and dietary fiber. It is confirmed that cereal polysaccharides like arabinoxylans and beta glucans maintain the proper levels of blood glucose, insulin, and cholesterol and positive impact on health because of being good source of dietary fiber (Cui and Wang 2009). Cereal polysaccharides have various functional characteristics and can act as stabilizers, thickeners, emulsifiers, and gelation in dairy, meat, and bakery products (Ahmad and Kaleem 2018; Nakashima et al. 2018; Sandford and Baird 1983).

7.3.1 Cereal Polysaccharides

Polysaccharides are polymers of carbohydrate molecules consisting of long chains of monosaccharide units linked by glycosidic α (1→4) bonds and yields constituent monomers and oligosaccharides upon hydrolysis by amylases. They are present in plants, animals, and microorganisms. Polysaccharides may contain all the monosaccharaides of same type (homopolysaccharide) or of different types (heteropolysaccharides). Polysaccharides in cereals have been divided into two different classes, namely starch and non-starch polysaccharides (NSP). Starch is mainly present in endosperm part while as non-starch polysaccharides are present in both cell wall of endosperm and bran layers of cereals (Hamaker et al. 2019). Starch is the major carbohydrate in grains making 65–70% of total carbohydrate followed by other polysaccharides like β glucans and arabinoxylans. Structural characteristics are attributed to the non-starch polysaccharides as they have the capability to interact with each other and also with other non-carbohydrate entities like lignans and proteins (Hamaker et al. 2019). Due to health beneficial potential of these bioactive polysaccharides in cereals, they are receiving much attention from researchers and scientists all over the world. Studies conducted by various researchers substantiated their role on health by acting as antidiabetic, antioxidant, and anticancer agents (Khan et al. 2019; Li et al. 2017; Chen and Raymond 2008). The bioactivity of cereal polysaccharides is influenced by the shape and size of polysaccharide in solution, linkage pattern of monomers, solubility, gelation, and viscosity (Wang et al. 2017, Zhang et al. 2017).

The non-starchy polysaccharide portion forms the dietary fiber part of cereal grains as Cordex Alimentarius Commission (CAC) defined dietary fiber as polysaccharide which cannot be absorbed by small intestines of humans. In order to stay healthy, WHO has recommended that a person should get 25 g of dietary fiber in everyday diet as it reduces the chances of developing diabetes, cardiovascular diseases, and colorectal cancer. Since meat is deprived of dietary fiber, it becomes one of the best options to incorporate cereals in meat and meat products to improve its health profile. Apart from health properties, cereal polysaccharides have gained a specific place from industrial point of view for their well-documented applications as thickeners, emulsifiers, gelation agents, and textural agents in various food formulations (Ahmad and Kaleem 2018; Nakashima et al. 2018). Cereal dietary fiber in meat can also enhance its textural characteristics like juiciness by improving water-holding capacity and reduction in cooking losses (Chevance et al. 2000). There are various mechanisms through which cereal polysaccharides ameliorate the technological functionalities of meat as shown (Fig. 7.1).

Various low-fat reformulated meat product like restructured meat emulsions incorporated with cereal dietary fibers along with other ingredients have been

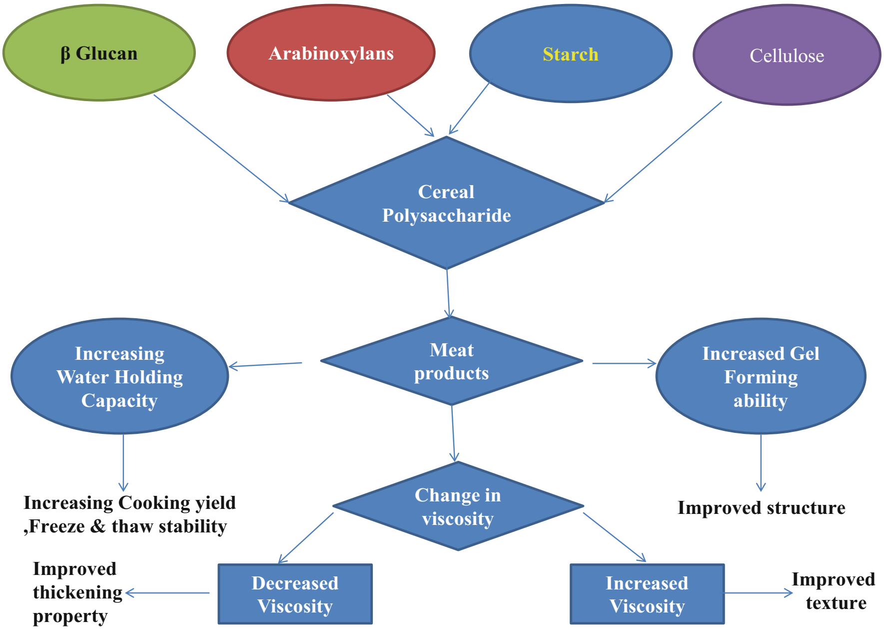


Fig. 7.1 Main mechanisms of improving various technological functionalities of meat products by different cereal polysaccharides (Adopted from Kaur and Sharma 2019)

studied (Sandford and Baird 1983). In this chapter, we will discuss some cereal polysaccharides like cellulose and hemicelluloses, especially β glucan and various other phytochemicals.

7.3.1.1 Starch

In cereals and grains, starch is the major polysaccharide among other carbohydrates (Pietrasik et al. 2012) with a calorific value of 4 cal/g and is easily digested in human gastrointestinal tract. Starch exists in plant tissues as granules of size 1–100 μm in diameter. Starch is composed of amylose and amylopectin both containing same monomers (D-glucose) but with different molecular weights and shape due to which they exhibit different functional properties (Petracci et al. 2013). Amylose being linear in shape can dissolve easily in solutions and can also align themselves by joining with each other through hydrogen bonding in gel matrix on heating, thereby providing enhanced gel strength in various food products and texture to the meat products with amylose-rich starches, while starches with high amylopectin are not able to align themselves as effectively as amylose, resulting in firm hydrogen bonding and less gel strength in food products. Starch can be isolated or extracted by adopting numerous methods like dough hand washing method in case of wheat enzymatic methods (Bechtel and Wilson 2000) and chemical buffer method (Zhao and Sharp 1996). In food industries, starch is most commonly used because of its good stabilizing effect and easy modification using various physical or chemical

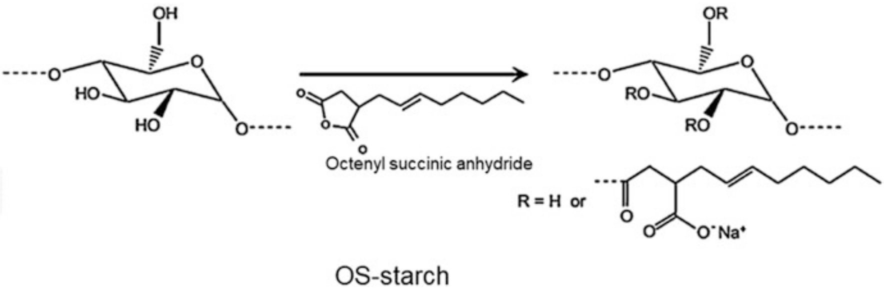


Fig. 7.2 Structure of starch modified with 2-Octen-1-yl succinic anhydride (OS-starch) (Adapted from Sweedman et al. 2013)

treatments. Starch acts as multifunctional ingredient in meat product development because of its wider applications like fat replacer (Jairath et al. 2018), emulsifying agent, water retention agent, and adhesive (Song et al. 2010).

Studies have shown that addition of cereal starch to meat products resulted in the decline in the cooking losses, leaching out of proteins and increased meat thaw stability (Li and Yeh 2003; Skrede 1989). Starch has found wide application in meat products as fat replacers as studies have suggested that starches having granular size same as that of fat emulsions can replace the fat in low-fat food without compromising the quality and sensory characteristics (Lindeboom et al. 2004; Malinski et al. 2003). This property of starch as fat replacer can be exploited in formulation of meat products by incorporating starch in native or modified form in them, for example corn starch was used as fat replacer in meat sausages which increased its water-binding capacity as starch has the ability to absorb water (Jairath et al. 2018). Starch in its native form is not as effective as it is in its modified form because it undergoes process of retrogradation on cooling, thereby affecting the quality of end products. So it becomes imperative to alter the chemical conformation of starch by physical or chemical means to overcome its limited applications in food industry, e.g. octenyl succinic anhydride (OSA) starch was modified by esterifying starch with octenyl succinic anhydride (Fig. 7.2). OSA starch has better functional properties as compared to native starch in terms of increased emulsifying ability and providing more compact structure with minimum pores in sausages (Song et al. 2010). Chemically modified starches on account of high hydration properties decreased purge and cooking losses in meat blocks which in turn improved color and textural properties. Some portion of starch which is not hydrolyzed to D-glucose in the intestines and is fermented in the colon is termed as resistant starch and is mostly present in legumes. Resistant starch present in unripe banana, rice, and potatoes comes under the category of dietary fiber. Resistant starch has the positive impact on colon as it increases the bulk in stool, lowers the pH of colon, and increases the cryptic cell production rate (Slavin et al. 2009). Resistant starch is metabolized by the micro flora of colon to short chain fatty acids like butyric acid and propionic acid which are in turn metabolized by the colonocyte especially butyric acid as energy source (Elmstahl 2002).

Resistant starch has several other beneficial effects on human health like

- Hypoglycemic effects (Sajilata et al. 2006)
- Acts as prebiotic
- Inhibits the accumulation of fat
- Hypocholestrolemic effect
- Reduction in gall stone formation (Sajilata et al. 2006)
- Enhances mineral absorption (Morais et al. 1996)

7.3.1.2 Cellulose

Cellulose finds an important application as food additive in various food formulations (Moncel 2019) and is one of the most abundant biomaterials on earth. Cellulose is present not only in plants but several bacteria also synthesize cellulose, of which most important and most extensively studied is *Acetobacter xylinum*. Bran layers of cereals like oats, rice, sorghum, and wheat contain large proportion of non-digestible cellulose (Claye et al. 1996). Cellulose extracted from cereals by alkali method is water-insoluble. Water-soluble carboxymethyl cellulose (CMC) is prepared from cellulose by heating with alkali, but it contains various other salts also, so for purification it is further treated with monochloroacetic acid which on esterification substitutes various hydroxyl groups with methyl carboxyl groups (Gibis et al. 2015). CMC has been approved as a food additive to be used in food products. One more common form cellulose called microcrystalline cellulose has been studied as a fat replacer in meat products (Barbut and Mittal 1996; Mittal and Barbut 1993) and in beef patties where its incorporation resulted in better textural and sensory profile in comparison to control samples (Gibis et al. 2015). It was also reported that MCC has more water-holding capacity as compared to CMC (Mittal and Barbut 1993), whereas another study showed only CMC was able to decrease the loss of moisture in frankfurters with low fat, with no considerable change in the color of reduced fat frankfurters by any of the cellulose forms (CMC, MCC); however, sensory scores were in the range of acceptance (Barbut and Mittal 1996). It has been suggested that while incorporating CMC and MCC in food products, their concentration and molecular weight may change the structural and quality of characteristics of these products quite considerably as CMC decreases the firmness of texture while as MCC maintains the coherence in protein gel network. Both these properties of cellulose can be exploited in the formulation of healthier reduced fat meat sausages (Schuh et al. 2013).

Other forms of cereal cellulose like amorphous cellulose when incorporated in meat products like sausages replaced with other fat enhanced the sensory and physiochemical properties due to its better water-retention ability (Torres 2002). Nowadays cellulose nanofibers owing to their good rheological, high strength, and good emulsifiability properties have got regenerated cellulose when incorporated into the reduced fat emulsified sausages provides more elastic and compact structure along with reduced cooking loss and high moisture content because of rheology of cellulose nanofibers and stabilizing effect of regenerated cellulose (Wang et al. 2018).

7.3.1.3 Hemicellulose

Cereal brans from Rye and wheat have gained tremendous interest for human consumption because of hemicellulose-rich dietary fiber. Hemicellulose is a non-starch polysaccharide present in bran layers of various cereals like rye, wheat, and barley as cell wall polysaccharide and accounts for 20–30% of total mass of plants (Spiridon and Popa 2008). Hemicellulose contain β(1–4) glycosidic bonds and include xylans, arabinoxylans, glucomannans, and β glucans. Hemicelluloses have been categorized into soluble and insoluble hemicelluloses as their extraction can be carried out in alkaline or neutral medium based on solubility (Vuorinen and Alen 1999). Very less proportion, 20–30%, of hemicellulose can be extracted by water because hemicelluloses are mostly linked to lignin via ferulic acid bridges and hydrogen bonding among non-substituted xyloses and cellulose chains (Nilsson et al. 1996; Maes and Delcour 2002).

Hemicelluloses from the bran of rice are said to have effect on the lowering of cholesterol level, thereby helping in removing the colon cancer (Hu and Yu 2013; Hu et al. 2007). It also has many industrial applications like gelling agent, tablet binder, and viscosity modifier (Revanappa and Salimath 2010). Hemicelluloses like arabinoxylans and β glucans have been used in many meat products.

β Glucans

Cereals as mentioned earlier are rich sources of dietary fiber with different concentrations in different cereals. β glucan is an important phytochemical in cereals mainly present in the aleurone and endospermic cell walls of cereals. Oats contain highest concentration of β glucan 14% on basis of dry mass followed by barley and wheat with 10% and 12%, respectively (Charalampopoulos et al. 2002). Beta glucan present in the cell walls of both endosperm and aleurone layers of barley contain levels up to 75% and 26%, respectively (Fincher 1992, Lazaridou et al. 2008). β glucan of barley is of high molecular weight (about 4 × 107 Da) with peptide sequence as part of its complex structure because of this proteolysis is the first step in its breakdown during digestion. β glucan from cereal grains contains *β*-(1→3) and *β*-(1→4) in an irregular fashion while as baker's yeast β glucan consists of *β*-(1→3) as well as (1→6) linkages (Gardiner 2004). Structurally β glucan is almost similar to cellulose with only difference of the twist provided by *β*-(1→3)-linkages in beta glucan thereby providing integrity to its structure and decreasing the tendency to form lumps. It is also advocated by some researchers that increased (1→4) linkages affect the solubility of β glucan owing to its intermolecular conglomeration (Staudte et al. 1983). β glucan is said to have effect on the viscous properties of the products in which it is added and usually depend on the solubility and molecular weight of the β glucans. Barley contains various endogenous enzymes which influence the viscosity of the products incorporated with barley flour slurries. On germination of barley endoenzymes *β*-(1→4)-glucanase is produced which hydrolyses the β glucan (Hrmova et al. 1997). Molecular weight of β glucan and melting temperature has been found to have direct relationship. Stabilizing the effect of temperature on viscosity of barley flour was also reported by some studies. Researches have pointed out that β glucan acts as immune system stimulator, antioxidant (Slamenova et al. 2003), anti-tumor agent (Chen 2013), antidiabetic, and hypo-cholesterol agent (Liatis et al. 2009). Owing to viscous behavior of β glucan in the human intestine, it has been reported to control blood sugar and cholesterol level. Intake of 5.8 g of β glucan on daily basis for 1 month through diet has been shown to reduce the cholesterol (LDL) levels in hypercholesterolemic persons (Braaten et al. 1994). Cholesterol-lowering ability of β glucan from oats has been attributed due to its ability of using cholesterol from the body for the synthesis of bile acids for restoring requisite levels of bile acids in the body (Drzikova et al. 2005). β glucan is helpful for diabetic patients as it has been suggested that it slows down the rate of stomach emptying, thereby delaying sugar absorption and thus helps in lowering blood sugar levels after taking meals (Braaten et al. 1994). β glucan from barley has been shown to make the human body resistant to insulin, thus helping diabetic patients in maintaining proper sugar levels (Ostman et al. 2006; Brennan and Cleary 2007; Hlebowicz and Darwiche 2008). Health claim about β glucan from oats that daily intake of 3 g β glucan per day lowers medical-related cholesterol concentration in serum, which have been approved by Food and Drug Administration (FDA 1997).

β glucans can be incorporated in various food items like sauces and beverages because of their various functionalities like emulsification, stabilizing, gelation and thickening and can also be used in meat products as hydrocolloids (Dawkins and Nnanna 1995; Burkus and Temelli 2000). Because of the health benefits attributed to the β glucan, cereals like barley and oats find a promising role in improving the quality of meat products in terms of health.

Arabinoxylans

Arabinoxylans (AX) categorized as dietary fiber are non-starch polysaccharides forming 70% cell wall NSPs. They form the component of cell walls of all major cereals like wheat, rye, sorghum, oats, and rice (Maes and Delcour 2002; Kaczmarek et al. 2016; Saulnier et al. 2007) with higher concentrations in rye and wheat. Structurally they have backbone of xylose residues associated with ferulic acid moieties, because of these moieties they possess antioxidant properties and therefore can be used in food products like meat to improve their quality by suppressing oxidative spoilage. Arabinoxylans have the distinctive ability of forming gels which have better water retention power and great stability against iconic charges and pH as they are formed by association of ferulic acid and arabinoxylans (Izydorczyk and Biliaderis 1995). Supplementation of meat sausages with 0.15% and 0.30% arabinoxylans leads to the formulation of product with improved antioxidant power, water-holding capacity, pH, titrable acidity, etc. (Herrera-Balandrano et al. 2018). It is also reported that arabinoxylans act as prebiotics by stimulating the growth of certain beneficial bacteria (*Bifidobacterium longnum*) in the human intestine (Mendis et al. 2016; Ou and Sun 2014). They may be helpful in preventing colon cancer by improving mucosal health as micro biota of intestines break them to short chain fatty acids which serve as energy reservoir for colon endothelial cells

(Loosveld et al. 1998). Arabinoxylans possess many other functions such as the following:

- They act as immune modulators by affecting various immune cells to increase their response (Mendis et al. 2016).
- They can lower glycemic index and cholesterol level owing to their high viscosity and solubility, thereby reducing chances of diabetes.
- Because of their ability to act as prebiotics, they lower the rate of cardiovascular diseases (Huang et al. 2015).

7.4 Other Phytochemicals in Cereals

7.4.1 Phenolics

Most of the phytochemicals in cereals are in bound form due to which they are mostly undermined and not counted in total phenolics. Among various other phytochemicals in cereals, phenolics are the most studied phytochemicals. Phenolics contain aromatic benzene ring with one or more hydroxyl groups attached to it, e.g., flavonoids, alkylresorcinols, phenolic acids, tocopherols, and avenanthramides (Slavin 2004). Oats contain a peculiar phytochemical avenanthramides which is a group of *N*-cinnamoylanthranilate alkaloids. Cereals are also rich in antioxidants which are mostly concentrated to bran layers. Antioxidants in cereals may be either water-soluble and fat-soluble (tocotrienols, flavonoids, tocopherols) or insoluble (cinnamic esters). Phenolics present in the bran layers of cereals have been found to have antioxidant properties in combination with other components present in them. Buckwheat contains a phenolic compound rutin mainly present in its leaves, and clinical data has shown its efficacy as antioxidant, edema protection, anti-inflammatory, and reduction of atherosclerosis.

Wheat bran insoluble fiber contains 0.5%–1.0% phenolics. Wheat bran has high antioxidant potential due to its high concentration of phenolics present in it such as alkylresorcinols, ferulic acids, ρ-coumaric acids, protocatechuic acid, and sinapic acids (Onyeneho and Hettiarachchy 1992). Most of the phytochemicals in cereals may be helpful in preventing various types of cancers especially colon cancer as they are not digested in the intestines because of being in bound form and therefore reach the colon where they can act as prebiotics (Kroon et al. 1997) Ferulic acid in addition to its antioxidant property has been shown to have the property of scavenging nitrites in acidic conditions (Moller et al. 1988) and therefore finds an important application in the cured meats where nitrites are said to be cancer-causing agents.

Proanthocyanidin (procyanidins and prodelphinidins) polyphenols present in bran layers of barley possess higher degree of antioxidant activity. The free radical scavenging property of Hordeumin, a polyphenolic (anthocyanin-tannin) purple pigment (Deguchi et al. 2000), produced during the fermentation of barley bran can be utilized in the prevention of free radical-mediated lipid peroxidation in meat products.

7.4.2 Lignans

Lignans are phenolic compounds which exist as secondary metabolites in various vascular plants. Lignan-rich foods like whole grain cereals are considered as protective foods having wide range of health benefits like reducing the chances of cardiovascular diseases (Adlercreutz 2007; Peterson et al. 2010). Lignans are diphenolic compounds formed by the association of two phenylpropanoid C6–C3 units and possess optical activity. Various lignans have been reported from wide range of foods like lariciresinol, matairesinol, pinoresinol, sesamin, syringarecinol, and secoisolariciresinol (Thompson et al. 2006; Milder et al. 2005). Oilseeds are the richest sources of lignans followed by cereal grains like oats and wheat barley. Among oil seeds, flax seed is the richest source of lignans especially secoisolariciresinol diglucoside and alpha linolenic acid (ALA). It has been found that colonic bacteria are able to convert plant lignans to enterodiol and enterolactone which are mammalian lignans by the process of de-glycosylation (Axelson et al. 1982; Borriello et al. 1985). Enterodiol is also converted to enterolactone and vice versa upon oxidation. Structurally enterodiol and enterolactone also called as enterolignans are analogous to estrogen hormone, thereby exhibiting estrogenic effects. Enterolignans are said to have several health-benefitting effects such as reduction in cardiovascular and hormone-initiated cancer (Webb and McCullough 2005). Flaxseed contain lignans and can be used in meat products as binders, thereby providing dual purpose of improving physiological characteristics as well as health profile of meat products.

7.4.3 γ Oryaznol

Earlier the husk from rice was discarded or burnt or used as animal feed, but with the advancement in science and technology the rice industry by-products like rice bran oil and rice bran have gained tremendous attraction among researchers for their high phytochemical content, e.g. γ oryzanol, carotenoids, and tocopherols. γ oryzanol has been reported from wheat bran rye bran also, but the concentration of γ oryzanol in rice bran is very high, 3000 mg/kg (Xu and Godber 1999). γ oryzanols are phenolic acids esterified to sterols and γ oryzanol from rice bran differ from that of wheat bran as sterols in rice bran oryazanols are dimethyl sterols, while oryzanols in wheat or rye are lacking in dimethyl groups. (Nystrom et al. 2005). The major components of γ oryzanol include 24-methylenecycloartanylferulate, campesteryl ferulate, and cycloartenyl ferulate. γ oryzanols have antioxidant, anticancer, and antitumor properties. It has been found that γ oryzanols have more antioxidative power than vitamin E as it prevented oxidation of cholesterol more convincingly (Xu et al. 2001). The antioxidant activity by γ oryzanols is attributed to the radical scavenging property of 24-methylenecycloartanyl ferulate and hampering of UV-assisted oxidation by campesteryl ferulate component (Yagi and Ohishi 1979). γ oryzanol has been shown to lower the cholesterol level in the human body as it has been reported that rice bran oil (RBO) can covert cholesterol into bile acids and also decrease dietary cholesterol absorption, thereby increasing high-density lipoprotein (HDL) and lowering low-density lipoprotein (LDL). Using proper food processing technologies, rice bran oil can be stabilized and latter incorporated into various food products like meat and bread, thereby preventing rancidity.

7.5 Conclusion

Cereals being staple component of the human diet worldwide contribute largely to the nutritional requirements of the population. Cereals contain significant amount of various phytochemicals including phenolics, carotenoids, lignans, and oryzanols. Cereals have been shown to have tremendous potential to act as antioxidant, thereby ameliorating the oxidative stability of the products containing them and consequently stalling the occurrence of various chronic diseases as free radicals formed on lipid peroxidation have been found to be the cause of various diseases. Meat is devoid of dietary fiber and various dietary fiber sources have been tried successfully in meat such as mousambi peel and apple pomace. Cereals contain good amount of dietary fiber especially β glucan in oats and have been shown to decrease the cholesterol levels in the body and also providing bulk to the fecal matter, thereby helping in the reduction in incidents of colorectal cancers which are the main concerns regarding meat consumption. Proper processing of cereal grains will also increase the bioavailability of phytochemicals in cereals. Much research is needed in the field of cereals to make them suitable for the development of functional meat products with health-benefitting properties. Further research is needed in investigating the ways to enhance the bioavailability cereal phytochemicals in meat products, thereby subduing the health implications associated with meat products.

Acknowledgment The corresponding author is grateful to U.G.C., New Delhi, for financial assistance in the form of Maulana Azad National Fellowship.

References

Adlercreutz H (2007) Lignans and human health. Crit Rev Clin Lab Sci 2007(44):483–525

Ahmad A, Kaleem M (2018) β-Glucan as a food ingredient. In: Grumezescu AM (ed) Biopolymers for food design, vol 20. Academic, Cambridge. https://doi.org/10.1016/B978-0-12-811449-0.00011-6

Axelson M, Sjövall J, Gustafs BE, Setchell KDR (1982) Origin of lignans in mammals and identification of a precursor from plants. Nature 298:659–660

Barbut S, Mittal GS (1996) Effects of three cellulose gums on the texture profile and sensory properties of low-fat frankfurters. Int J Food Sci Technol 31(3):241–247. https://doi.org/10.1046/j.1365-2621.1996.00337.x

Bechtel DB, Wilson J (2000) Variability in a starch isolation method and automated digital image analysis system used for the study of starch size distributions in wheat flour. Cereal Chem 77(3):401–405. https://doi.org/10.1094/CCHEM.2000.77.3.401

Boada LD, Henríquez-Hernández LA, Luzardo OP (2016) The impact of red and processed meat consumption on cancer and other health outcomes: epidemiological evidence. Food Chem Toxicol 92:236–244. https://doi.org/10.1016/j.fct.2016.04.008
Borriello SP, Setchell KDR, Axelson M, Lawson AMJ (1985) Production and metabolism of lignans by the human faecal flora. Appl Bacteriol 58:37–43
Bouvard V, Loomis D, Guyton KZ, Grosse Y, Ghissassi FE, Tallaa LB, Guha N, Mattock H, Straif K (2015) International Agency for Research on Cancer Monograph Working Group, Carcinogenicity of consumption of red and processed meat. Lancet Oncol 16:1599–1600
Boyle E (1994) The nutritive value of meat. Dept. of Animal science and industry, Kansas State University, USA
Braaten JT, Wood PJ, Scott FW, Wolynetz MS, Lowe MK, Bradley-White P, Collins MW (1994) Oat beta-glucan reduces blood cholesterol concentration in hypercholesterolemic subjects. Eur J Clin Nutr 48:465–474
Brennan CS, Cleary LJ (2007) Utilization of Glucagel in the β-glucan enrichment of breads: a physicochemical and nutritional evaluation. Food Res Int 40(2):291–296
Burkus Z, Temelli F (2000) Stabilization of emulsions and foams using barley beta-glucan. Food Res Int 33:27–33
Charalampopoulos D, Wang R, Pandiella SS, Webb C (2002) Application of cereals and cereal components in functional foods: a review. Int J Food Microbiol 79(1–2):131–141
Charalampopoulos D, Wang R, Pandiella SS, Webb C (2019) Application of cereals and cereal components in functional foods: a review. Int J Food Microbiol 79(1–2):131–141
Chen J (2013) Recent advances in studies of β-glucans for cancer therapy. Anticancer Agents Med Chem 13(5):679–680. https://doi.org/10.2174/1871520611313050001
Chen J, Raymond K (2008) Beta-glucans in the treatment of diabetes and associated cardiovascular risks. Vasc Health Risk Manag 4(6):1265–1272
Chevance FF, Farmer LJ, Desmond EM, Novelli E, Troy DJ, Chizzolini R (2000) Effect of some fat replacers on the release of volatile aroma compounds from low-fat meat products. J Agric Food Chem 48(8):3476–3484. https://doi.org/10.1021/jf991211u
Claye SS, Idouraine A, Weber CW (1996) Extraction and fractionation of insoluble fiber from fiber sources. Food Chem 57(2):305–310. https://doi.org/10.1016/0308-8146(95)00250-2
Cui SW, Wang Q (2009) Cell wall polysaccharides in cereals: chemical structures and functional properties. Struct Chem 20(2):291–297. https://doi.org/10.1007/s11224-009-9441-0
DADF (2017) Annual report. DADF, Ministry of Agriculture, Government of India
DADF (2018) 20th Livestock census. DADF, Ministry of Agriculture, Government of India
Dawkins NL, Nnanna IA (1995) Studies on oat gum (1→3, 1→4)- β-d glucan: composition, molecular weight estimation and rheological properties. Food Hydrocoll 9(1):1–7
Deguchi T, Ohba R, Ueda S (2000) Radical scavenging activity of a purple pigment, Hordeumin, from uncooked barley bran-fermented broth. J Agric Food Chem 48(8):3198–3201
Drzikova B, Dongowski G, Gebhardt E, Habel A (2005) The composition of dietary fiber-rich extrudates from oat affects bile acid binding and fermentation in vitro. Food Chem 90:181–192
Elmstahl HL (2002) Resistant starch content in a selection of starchy foods on the Swedish market. Eur J Clin Nutr 56:500–505
FDA (1997) FDA allows whole oat foods to make health claim on reducing the risk of heart disease. FDA Talk Paper, In
Fincher GB (1992) Cell wall metabolism in barley. In: Shewry PR (ed) Barley genetics, biochemistry, molecular biology and biotechnology. CAB International, Wallingford, pp 413–437
Gardiner T (2004) Beta-glucan biological activities: a review, pp 1–39. Accessed from www.usa.glycoscience
Gibis M, Schuh V, Weiss J (2015) Effects of carboxymethyl cellulose (CMC) and microcrystalline cellulose (MCC) as fat replacers on the microstructure and sensory characteristics of fried beef patties. Food Hydrocoll 45:236–246. https://doi.org/10.1016/j.foodhyd.2014.11.021

Godfray HCJ, Aveyard P, Garnett T, Hall JW, Key TJ, Lorimer J, Pierrehumbert RT, Scarborough P, Springmann M, Jebb SA (2018) Meat consumption, health and environment. Science 361(6399). pii: eaam5324. https://doi.org/10.1126/science.aam5324

Grasso S, Brunton NP, Lyng JG, Lalor F, Monahan FJ (2014) Healthy processed meat products—regulatory, reformulation and consumer challenges. Trends Food Sci Technol 39(1):4–17. https://doi.org/10.1016/j.tifs.2014.06.006

Hamaker BR, Tuncil YE, Shen X (2019) Carbohydrates of the kernel. In: Corn. Woodhead Publishing, Duxford, pp 305–318. https://doi.org/10.1016/b978-0-12-811971-6.00011-5

Herrera-Balandrano DD, Báez-González JG, Carvajal-Millán E, Rangel DM, Orona VU, Lopez ALM, Escalante JAM (2018) Alkali-extracted feruloylated arabinoxylans from nixtamalized maize bran byproduct: a synonymous with soluble antioxidant dietary fiber. Waste Biomass Valoriz. https://doi.org/10.1007/s12649-018-0462-z

Hlebowicz J, Darwiche G, Björgell O, Almér L (2008) Effect of muesli with 4 g oat β-glucan on postprandial blood glucose, gastric emptying and satiety in healthy subjects: a randomized crossover trial. J Am Coll Nutr 27(4):470–475

Hrmova M, Banik M, Harvey AJ, Garrett TPJ, Varghese JN, Hoj PB, Fincher GB (1997) Polysaccharide hydrolases in germinated barley and their role in the depolymerization of plant and fungal cell walls. Int J Biol Macromol 21:67–72

Hu GH, Yu WJ (2013) Binding of cholesterol and bile acid to hemicelluloses from rice bran. Int J Food Sci Nutr 64:461–466. https://doi.org/10.3109/09637486.2012.749838

Hu GH, Yang F, Ma ZZ, Zhou Q (2007) Development of research and application of rice bran dietary fiber. China Food Additives 84:80–85

Huang T, Xu M, Lee A, Cho S, Qi L (2015) Consumption of whole grains and cereal Fiber and Total and cause-specific mortality: prospective analysis of 367,442 individuals. BMC Med 13 (1):85

Hur SJ, Lim BO, Park GB, Joo ST (2009) Effect of various fiber additions on lipid digestion during in *vitro* digestion of beef patties. J Food Sci 74(9):C653–C657

Izydorczyk MS, Biliaderis CG (1995) Cereal arabinoxylans: advances in structure and physicochemical properties. Carbohydr Polym 28(1):3348. https://doi.org/10.1016/0144-8617(95)00077-1

Jairath G, Sharma DP, Dabur RS, Singh PK, Bishnoi S (2018) Standardization of corn starch as a fat replacer in buffalo calf meat sausages and its effect on the quality attributes. Indian J Anim Res 52:1521–1525. https://doi.org/10.18805/ijar.B-3381

Johnson IT, Southgate DAT (1994) Dietary fiber and related substances. In: Edelman J, Miller S (eds) food safety science. Champman & Hill, London, pp 39–65

Kaczmarek R, Komisarczyk J, Nebesny A, Bartlomiej ME (2016) Influence of Arabinoxylans on the quality of grain industry products. Eur Food Res Technol 2016:242(3)

Kaeferstein FK, Clugston GA (1995) Human health problems related to meat production and consumption. Fleischwirtschaft Technol 75:889–892

Kaur R, Sharma M (2019) Cereal polysaccharides as functional ingredient for reformulation of meat products: a review. J Funct Foods 62(2019):103527

Khan T, Date A, Chawda H, Patel K (2019) Polysaccharides as potential anticancer agents—A review of their progress. Carbohydr Polym 210:412–428. https://doi.org/10.1016/j.carbpol.2019.01.064

Kroon PA, Faulds CB, Ryden P, Robertson JA, Williamson G (1997) Release of covalently bound Ferulic acid from Fiber in the human Colon. J Agric Food Chem 45:661–667

Kumar R, Prasad S, Kumar S (2018) Present status of Indian meat industry a review. Int J Curr Microbiol App Sci 7:4627–4634

Lazaridou A, Chornick T, Biliaderis CG, Izydorczyk MS (2008) Composition and molecular structure of polysaccharides released from barley endosperm cell walls by sequential extraction with water, malt enzymes, and alkali. J Cer Sci 48:304–318. https://doi.org/10.1016/j.jcs.2007.09.011

Li JY, Yeh AI (2003) Effects of starch properties on rheological characteristics of starch/meat complexes. J Food Eng 57:287–294. https://doi.org/10.1016/S0260-8774(02)00309-6
Li H, Ding F, Xiao L, Shi R, Wang H, Han W, Huang Z (2017) Food-derived antioxidant polysaccharides and their pharmacological potential in neurodegenerative diseases. Nutrients 9(7):778. https://doi.org/10.3390/nu9070778
Liatis S, Tsapogas P, Chala E, Dimosthenopoulos C, Kyriakopoulos K, Kapantais E, Katsilambros N (2009) The consumption of bread enriched with β-glucan reduces LDL-cholesterol and improves insulin resistance in patients with type 2 diabetes. Diabetes Metab 35:115–120
Lindeboom N, Chang PR, Tyler RT (2004) Analytical, biochemical and physicochemical aspects of starch granule size, with emphasis on small granule starches: a review. Starch 56(34):89–99. https://doi.org/10.1002/star.200300218
Loosveld A, Maes C, Van-Casteren WHM, Schols HA, Grobet PJ, Delcour JA (1998) Structural variation and levels of water-extractable Arabinogalactan-peptide in European wheat flours. Cereal Chem 75(6):815–819. https://doi.org/10.1094/CCHEM.1998.75.6.815
Maes C, Delcour JA (2002) Structural characterisation of water-extractable and water-unextractable arabinoxylans in wheat bran. J Cereal Sci 35(3):315–326
Malinski E, Daniel JR, Zhang XX, Whistler RL (2003) Isolation of small starch granules and determination of their fat mimic characteristics. Cer Chem J 80(1):1–4. https://doi.org/10.1094/cchem.2003.80.1.1
Mendis M, Leclerc E, Simsek S (2016) Arabinoxylans, Gut microbiota and immunity. Carbohydr Polym 30(139):159–166. https://doi.org/10.1016/j.carbpol.2015.11.068
Milder IE, Arts IC, van de Putte B, Venema DP, Hollman PC (2005) Lignan contents of Dutch plant foods: a database including lariciresinol, pinoresinol, secoisolariciresinol and matairesinol. Br J Nutr 2005(93):393–402
Mittal GS, Barbut S (1993) Effects of various cellulose gums on the quality para-meters of low-fat breakfast sausages. Meat Sci 35(1):93–103. https://doi.org/10.1016/0309-1740(93)90072-p
Moller ME, Dahl R, Bockman OC (1988) A possible role of the dietary Fiber product, wheat bran, as a nitrite scavenger. Food Chem Toxicol 26(10):841–845
Moncel B (2019). Retrieved from https://www.thespruceeats.com/what-is-cellulose-1328464 on May 12, 2019
Morais MB, Feste A, Miller RG, Lifichitz CH (1996) Effect of resistant starch and digestible starch on intestinal absorption of calcium, iron and zinc in infant pigs. Paediatr Res 39(5):872–876
Nakashima A, Yamada K, Iwata O, Sugimoto R, Atsuji K, Ogawa T, Suzuki K (2018) β-Glucan in foods and its physiological functions. J Nutr Sci Vitaminol 64(1):8–17. https://doi.org/10.3177/jnsv.64.8
Nilsson M, Saulnier L, Andersson R, Åman P (1996) Water unextractable polysaccharides from three milling fractions of rye grain. Carbohydr Polym 30:229–237
Nystrom L, Makinen M, Lampi AM, Piironen V (2005) Antioxidant activity of steryl ferulate extracts from rye and wheat bran. J Agric Food Chem 53:2503–2510
Onyeneho SN, Hettiarachchy NS (1992) Antioxidant activity in durum wheat bran. J Agric Food Chem 40(9):1496–1500
Ostman E, Rossi E, Larsson H, Brighenti F, Bjorck I (2006) Glucose and insulin response in healthy men to barley bread with different levels of (1→3) (1→4)- β-glucans; predictions using fluidity measurements of in vitro enzyme digests. J Cereal Sci 43:230–235
Ou J, Sun Z (2014) Feruloylated oligosaccharides: structure: metabolism and function. J Funct Foods 2014(7):90–100. https://doi.org/10.1016/j.jff.2013.09.028
Peterson J, Dwyer J, Adlercreutz H, Scalbert A, Jacques P, McCullough ML (2010) Dietary lignans: physiology and potential for cardiovascular disease risk reduction. Nutr Rev 68:571–603
Petracci M, Bianchi M, Mudalal S, Cavani C (2013) Functional ingredients for poultry meat products. Trends Food Sci Technol 33(1):27–39. https://doi.org/10.1016/j.tifs.2013.06.004
Pietrasik Z, Pierce DL, Janz JAM (2012) The effect of selected starches on hydration, textural and sensory characteristics of restructured beef products. J Food Qual 35(6):411–418. https://doi.org/10.1111/jfq.12000

Revanappa SB, Salimath PV (2010) Structural characterization of hemicellulose A from wheat (*Triticum aestivum*) varieties differing in their chapati-making quality. Carbohydr Polym 79 (3):655–659

Sajilata MG, Singhal RS, Kulkarni PR (2006) Resistant starch—a review. Compr Rev Food Sci Food Saf 5:1–17

Sandford PA, Baird J (1983) Industrial utilization of polysaccharides. In: The Polysaccharides. Academic Press, New York, pp 411–490. https://doi.org/10.1016/b978-0-12-065602-8.50012-1

Saulnier L, Sado PE, Branlard G, Charmet G, Guillon F (2007) Wheat Arabinoxylans: exploiting variation in amount and composition to develop enhanced varieties. J Cereal Sci 46(3):261–281. https://doi.org/10.1016/j.jcs.2007.06.014

Schuh V, Allard K, Herrmann K, Gibis M, Kohlus R, Weiss J (2013) Impact of carboxymethyl cellulose (CMC) and microcrystalline cellulose (MCC) on functional characteristics of emulsified sausages. Meat Sci 93(2):240–247. https://doi.org/10.1016/j.meatsci.2012.08.025

Singh A (2018) Current livestock production statistics of India; Accessed at http://www.vetextension.com/current-livestock-animal-husbandry-statistics-india

Skrede G (1989) Comparison of various types of starch when used in meat sausages. Meat Sci 25 (1):21–36. https://doi.org/10.1016/0309-1740(89)90063-6

Slamenova D, Labaj J, Krizkova L, Kogan G, Sandula J, Bresgen N, Eckl P (2003) Protective effects of fungal (1→3) β-D-glucan derivatives against oxidative DNA lesions in V79 hamster lung cells. Cancer Lett 198:153–160

Slavin J (2004) Whole grains and human health. Nutr Res Rev 17:99–110

Slavin J, Stewart M, Timm D, Hospattankar A (2009) Fermentation patterns and short chain-fatty acid profiles of wheat dextrin and other functional fibers. In: Proceedings of 4th International dietary fiber conference 2009, p. 35. International Association for Cereal Science and Technology (ICC), 1–3 July 2009, Vienna, Austria

Song X, Zhu W, Li Z, Zhu J (2010) Characteristics and application of octenyl succinic anhydride modified waxy corn starch in sausage. Starch 62(12):629–636. https://doi.org/10.1002/star.201000043

Spiridon I, Popa VI (2008) Hemicelluloses: major sources, properties and applications. In: Belgacem MN, Gandini A (eds) Monomers, polymers and composites from renewable resources. Elsevier, Oxford, pp 289–304. https://doi.org/10.1016/B978-0-08-045316-3.00013-2

Staudte RG, Woodward JR, Fincher GB, Stone BA (1983) Water soluble (1→3), (1→4)-*β*-glucan from barley (*Hordeum vulgare*) endosperm III. Distribution of cellotriosyl and cellotetraosyl residues. Carbohydr Polym 3:299–312

Sweedman MC, Hasjim J, Tizzotti MJ, Schäfer C, Gilbert RG (2013) Effect of octenylsuccinic anhydride modification on β-amylolysis of starch. Carbohydr Polym 97(1):9–17

Thompson LU, Boucher BA, Liu Z, Cotterchio M, Kreiger N (2006) Phytoestrogen content of foods consumed in Canada, including isoflavones, lignans and coumestan. Nutr Cancer 54:184–201

Torres EAFS (2002) Alimentos do milênio: Aimportância dos transgênicos, funcionais efitoterápicos para a saúde. SignusEditora, São Paulo

Vuorinen T, Alen R (1999) Carbohydrates. In: Sjostrom E, Alen R (eds) Analytical methods in wood chemistry, pulping, and papermaking, vol III. Springer, Berlin, p 37

Wang Z, Klipfell E, Bennett BJ, Koeth R, Levison BS, Dugar B, Feldstein AE, Britt EB, Fu X, Chung YM, Wu Y, Schauer P, Smith JD, Allayee H, Tang WHW, DiDonato JA, Lusis AJ, Hazen SL (2011) Gut flora metabolism of phosphatidylcholine promotes cardiovascular disease. Nature 472(57–63)

Wang Q, Sheng X, Shi A, Hu H, Yang Y, Liu L, Liu H (2017) β-Glucans: relationships between modification, conformation and functional activities. Molecules 22(2):257. https://doi.org/10.3390/molecules22020257

Wang Y, Wang W, Jia H, Gao G, Wang X, Zhang X, Wang Y (2018) Using cellulose nanofibers and its palm oil Pickering emulsion as fat substitutes in emulsified sausage. J Food Sci 83 (6):1740–1747

Webb AL, McCullough ML (2005) Dietary lignans: potential role in cancer prevention. Nutr Cancer 51:117–131

Wolk A (2017) Potential health hazards of eating red meat. J Intern Med 281:106–122

Xu Z, Godber JS (1999) Purification and identification of components of gamma-oryzanol in rice bran oil. J Agric Food Chem 47:2724–2728

Xu Z, Hua N, Godber JS (2001) Antioxidant activity of tocopherols, tocotrienols and gamma-oryzanol components from rice bran against cholesterol oxidation accelerated by 2,2-azobis (2-methylpropionamidine) dihydrochloride. J Agric Food Chem 49:2077–2081

Yagi K, Ohishi N (1979) Action of ferulic acid and its derivatives as antioxidants. J Nutr Sci Vitaminol (Tokyo) 25:127–130

Zhang ZP, Shen CC, Gao FL, Wei H, Ren DF, Lu J (2017) Isolation, purification and structural characterization of two novel water-soluble polysaccharides from anrederacordifolia. Molecules 22(8):1276

Zhao XC, Sharp PJ (1996) An improved 1-D SDS–PAGE method for the identification of three bread wheat «waxy» proteins. J Cereal Sci 23(2):191–193. https://doi.org/10.1006/jcrs.1996.0019

Role of Dietary Fibers and Their Preventive Measures of Human Diet

8

Saghir Ahmad and Irfan Khan

Abstract

The dietary fiber is the most important component of human diet. Dietary fibers are the indigestible carbohydrates that cannot be hydrolyzed by the endogenous enzymes in the human intestine but can be utilized by the microflora present in the human gut. Nowadays, people are suffering with several metabolic disorders due to lack of dietary fibers in the diet. The dietary fibers play an important role in the human metabolism by providing cleansing action and making regular in the morning. Constipation is the major problem that happens with the diet devoid of dietary fibers. Globally, people are suffering with several types of non-communicable diseases due to fiber-free diet viz., cardiovascular diseases, type II diabetes mellitus, cancer, etc. The consumers have now become conscious about their health and trend and it is continuously being changed in the food processing sector. The food processing industries have started to make food enriched with fiber, for consideration of human health. There are some food that lacks in dietary fibers viz., meat, milk, fish, and egg completely devoid of dietary fibers. So it is the responsibility of food technologists and food processors to fulfill the need of today by making such food products that carry the sufficient amount of dietary fibers and must have appealing taste and flavor to attract the consumers. This chapter will cover the role of dietary fibers on body metabolism in the prevention of several types of non-communicable diseases.

Keywords

Dietary fibers · Carbohydrates · Cellulose · Human health

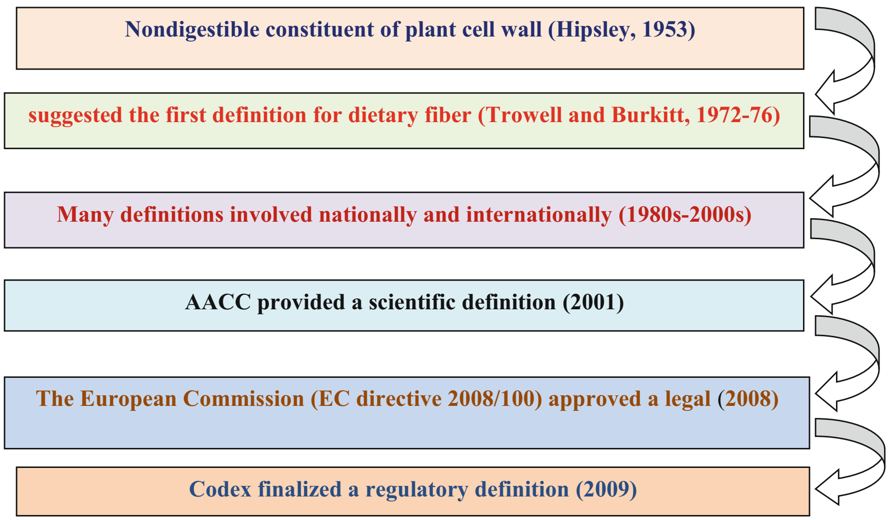
S. Ahmad (✉) · I. Khan
Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_8

8.1 Introduction

Fiber is being an important part of human diet and is available in fruits and vegetables, and whole grain and several other foods. There are several examples of dietary fiber being present in processed foods such as Britannia Nutrichoice biscuit which has been added with fiber. The important health benefits of dietary fibers are: (1) it helps to maintain healthy weight, (2) relieve constipation, (3) lowers the risk of diabetes, (4) heart diseases, and (5) some types of cancer.

The dietary fibers are also recognized as roughage that is included as part of a plant or whole plant like chili. The dietary fibers as roughage is not digested in the human digestive system contrary to carbohydrate, protein, and lipid which is assimilated and provides energy in the form of calories as well as chemical energy that fulfills the requirement of body like minerals, vitamins, pigments, antioxidants, amino acids, etc. Many research bodies, including the US FDA, FOA/WHO, the food standards project, the Codex Alimentarius Commission, and the European Food Safety Authority (EFSA), tried to provide a clear definition for scientific and/or regulatory purposes, including the American Association of Cereal Chemist's, the American Institute of Medicine, and the American Academy of Regulatory Species. The following examples include the various stages of evolution (Spiller 2001; van der Kamp 2004; Brownlee 2011; Phillips and Cui 2011) as given below in chronological manner.



The committees recommend that these edible parts of plants in human digestive system are not absorbed or released no energy in the form of calories. They go along the intestinal tract and make a bulk in intestine system to channelize the stool for proper discharge. This is the reason that food fiber material makes key physiological

Table 8.1 Daily recommendation of dietary fiber for adults

	Age	
	50 or young (g)	51 or old (g)
Men	38	30
Women	25	21

impacts on human health. The requirement of dietary fiber for human is given below in Table 8.1.

The dietary fiber are categorized as soluble dietary fibers and insoluble dietary fibers. The soluble fraction forms a gel-like material by dissolving in water. It can help in lowering the serum cholesterol and glucose level of blood. The typical sources of soluble fibers are the cereals like oats, barley and psyllium, vegetables like peas, beans, carrots, and fruits such as apples and citrus fruits. The chief specialty of insoluble dietary fibers is found to promote the material mobility through digestive tract and increase the size of stool. It has already been proved to remove the constipation.

8.2 General Understanding of Dietary Fiber

The carbohydrates in the GI tract can simply be divided into two basic groups. The first group such as monosaccharide, oligosaccharide, and polysaccharides viz., fructans and starch are digested by the intestinal enzymes and assimilated by the small intestine of human beings. Such molecules are known as non-fibrous polysaccharides and non-structural carbohydrates. The second group of carbohydrate is immune to the intestinal enzymes and acts as prebiotic substances for bacterial in large intestine, i.e., hemicelluloses, cellulose, pectin, lignin, etc. Such compounds can be called complex carbon hydrates and representative of neutral detergent fiber (NDF) acid detergent fibers (ADF), non-starch polysaccharides (NSP), and structural carbohydrate (Tseng and Zhao 2013). The neutral detergent fiber consists of hemicellulose, cellulose, and lignin while acid detergent fibers consist of lignin and cellulose. However, both the above analysis is commonly used in animal nutrition and roughage analyses. This role was a divergent method and relied on both the principle of nutrition and research. Nutritional physiology is the simplest and the most important concept. Nevertheless, chemists and regulators have learned to the study of dietary fiber factually. The concept of physiology can be understood and accepted by the general public in practice.

8.3 Different Sources of Dietary Fibers

Fibers, the indigestible carbohydrates, can be extracted from variety of plant sources such as cereals, vegetables, legumes, fruits with varying degree of soluble and insoluble fibers. The scientists have given their attention on the variety of dietary fiber and its benefits to get the sustainable life style. Recent work has started to isolate these components and to assess if an improvement in their diet benefits human health. The isolation of these fractions suggests better understanding of dietary fibers.

8.3.1 Inulin

Inulins are the group of naturally occurring polysaccharides, obtained from different sources such as fruits, vegetables, herbs like onion, garlic and cereals viz., wheat, artichoke, and bananas. It is utilized for various applications like producing the processed food products due to having unique nutritional attributes. As inulins did not cause any technological side effects, so it is used to produce food products without affecting taste and texture, as a substitute for fat or soluble carbohydrates and continue to contribute to a food nutritional value. Enzyme hydrolysis is low (<10%) in the small intestines since inulin produces beta bonds. It thus joins the large intestine and is metabolized almost entirely by microflora. In fermentations, propionate development is promoted and the ratio of acetate to propionate is reduced which contributes to a decrease in cholesterol and LDL level, one of the most limiting factors for the risk of cardiovascular diseases. Inulin has been shown to contribute as a prebiotic to human big bowel safety (Gibson and Roberfroid 1995). The results showed that inulin acts as prebiotic substrate that enhance the growth of beneficial bacteria while restrict the proliferation of harmful bacteria such as *Escherichia coli*. For adolescent girls with inulin supplement, calcium absorption was improved by approximately 20% (Griffin et al. 2003). Abrams et al. (2005) advocated the similar findings in which they confirmed such findings after a longer analysis of both boys and girls at the age of puberty by using an inulin supplement as compared to the control. The exact reason is still unknown but the scientists suggested the role of calcium absorption from the colon section. Eventually, absorption can be increased by enhancing vitamin D. The mechanism for preventing and managing obesity can also be inulin. Cani et al. (2006) have shown that in adults oligofructose, an inulin subgroup, which has induced a decrease in the total energy intake has increased.

8.3.2 Arabinoxylan

Arabinoxylan is hemicelluloses found both in primary and secondary cell wall of plants. Its backbone and side chains are made up of xylose and arabinose, respectively. It covers the greater fraction of dietary fibers in cereal grains with substantial endosperm and bran inclusions. *Triticum* species (wheat) holds the 64–69% of arabinoxylan in the bran and approximately 88% present in endosperm part (Ring and Selvendran 1980). Greater fraction of the arabinoxylan is removed as a by-product during normal wheat flour processing. Arabinoxylan is similar in the GI tract to a soluble fiber fermented rapidly through the colon's microflora.

The reverse relation of intake of arabinoxylan-rich bread with postprandial glucose in healthy adults was observed by Lu et al. (2000). A supplement of just 6 g of arabinoxylan-rich fiber, the postprandial glucose levels were significantly found lower as compared to the control. However, the 12 g supplement of the same was found with better effects on human health. For adults with an already impaired glucose tolerance, high arabinoxylan brooms also seem to control blood glucose and insulin (Lu et al. 2004). The fiber-rich arabinoxylan fiber applied to adults with type 2 diabetes. Glucose, postprandial glucose, and insulin were substantially lower. The mode of action behind arabinoxylan on improving glucose tolerance is yet to be discovered. The high viscosity of the fiber in the GI lumen, however, is thought to slow the glucose absorption rate. The comparatively lower value of glycemic index for arabinoxylan may also play a role in the glucose tolerance. The breads with arabinoxylan-rich flour shows a relatively lower value of glycemic index, i.e., 59. Although whole wheat flour has a glycemic index of nearly 99 (Lu et al. 2000). The bread rich in arabinoxylan is found with comparable glycemic index to that of whole grain bread. Although it has some obvious benefits viz., better organoleptic properties such as mouth feel, tenderness, etc. Lu et al. (2000) reported that no considerable difference was found in organoleptic properties of treated bread with 14% arabinoxylan-rich fiber as compared to control.

8.3.3 Beta Glucan

The beta glucan is a glucose monomeric polymer with beta (1→3) and beta (1→4) linkages and present in cereal's endosperm such as oats and barley. The amount of beta glucan range from 3.9 to 6.8% in North American oat cultivars (Wood et al. 1991). Beta glucan has been found to show its solubility towards polar solvents like water along with immensely viscous at low concentrations (Doublier and Wood 1995).

Beta glucan impacts the lipid metabolism along with postprandial glucose metabolism to improve the physiological functions of human body. Several studies suggested an inverse relationship between the levels of cholesterol and consumption of beta glucan. Some latest findings suggested a significant reduction of serum total and LDL cholesterol level by daily consumption of 5 g of beta glucan in both hypercholesterolemic (Theuwissen and Mensink 2007) and healthy (Naumann et al. 2006). similar findings have been proposed by Tappy (1995) in type II diabetes mellitus individuals who took the 4.0, 6.0, or 8.4 g of beta glucan in their diet. In contrast to above study, Davidson and McDonald (1998) advocated the similar results with 3.6 g of beta glucan significantly. Consequently, Biorklund et al. (2005) claimed the similar results in support of previous claims which stated the significant decrease in the postprandial glucose and insulin levels by consuming 5 g of beta glucan.

The viscosity of beta glucan has been observed one of the most important properties to improve the blood cholesterol and postprandial glucose metabolism. This gel-making attribute of beta glucan may help to decrease bile acid absorption by excreting the bile acids and increasing the intestinal viscosity. It leads to a greater synthesis of cholesterol by hepatic cells since the synthesis of bile acid is more important for general body metabolism (Lia et al. 1995). The viscosity of beta glucan may also delay glucose absorption and thus lowering the postprandial glucose and insulin levels into the blood. It was found that added to an oat concentrate cereal incorporate with 5 g of oat beta glucan significantly delayed the total glucose absorption by intestinal tract (Nazare et al. (2009). Similar results has been claimed that 5 g of beta glucan derived from oats significantly lowered the total serum cholesterol, postprandial glucose, and insulin levels while the same level of beta glucan derived from barley did not produce any significant affect (Biorklund et al. (2005). The beta glucan may also be found to show the related metabolic effects due to the production of short-chain fatty acids. Propionate was significantly found to inhibit cholesterol synthesis in human beings (Story et al. 1997) and supposed to be due to the competitive inhibition of HMG CoA reductase enzyme in liver cells (Ide et al. 1978). Keogh et al. (2003) has experimentally proved the inhibitory effect of beta glucan obtained from barley in 8.1–11.9 g/day quantity on the total cholesterol or LDL levels in subjects with mild hyperlipidemia. The 3.5 g of oat beta glucan incorporated to soup did not alter serum lipid profiles and the postprandial glucose levels as well (Cugnet-Anceau et al. 2010). The molecular weight can be affected by several factors such as processing of food and also the source of the beta glucan from where the product is harvested. Suortti et al. (2000) stated that food processing procedures viz., heating as in case of baking and extrusion, decreases the molecular weight of beta glucan and thereby reducing its viscosity inside the gastrointestinal tract of human beings. Beta glucan obtained through a dry milling process was used for various research purposes that did not significantly degrade the quality of beta glucan (Theuwissen and Mensink 2007; Naumann et al. (2006). However, Keogh et al. (2003) obtained the hot water extracted beta glucan that may have reduced the molecular weight of beta glucan. A number of researches suggested that bread baking process was found to lower the molecular weight of beta glucan. Unfortunately, this study failed to list the molecular weight of the beta glucan in the orange juice. Beta glucan obtained from different sources may also differ in their molecular weight and viscosity properties. Theuwissen and Mensink (2007) and Naumann et al. (2006) used the oat for the studies while barley beta glucan was used by Keogh et al. (2003). Since the molecular weight may have different values among the oat varieties (Yao et al. 2007). Beta glucan obtained from barley and oats differ in their solubility that may have a direct effect on intestinal viscosity. The solubility of barely beta glucan was significantly found higher than that of oats Gajdošová et al. (2007). Yao et al. (2007) found large difference in viscosity of beta glucan solutions from different oat varieties due to difference in the molecular weights. Törrönen et al. (1992) did not find any change using a lower MW (370,000 Da) beta glucan in serum lipid profiles in men with mild-to-moderate hypercholesterolemia when compared to a control.

8.3.4 Pectin

Pectin is the polymer of galacturonic acid units joined with α 1,4 linkages. Pectin has been found to show resistance against the enzymatic digestion in small intestine but is easily degraded by the colon microflora. Citrus fruits have pectin content in the range of 0.5–3.5% with greater concentration in the peel. Commercially extracted pectins are available in the market and utilizing in various food applications as a gelling or a thickening agent. The pectin maintains its ability to form a gel or thicken a solution inside the gastrointestinal tract. The gelling property is thought to be responsible for its beneficial effects on human health including dumping syndrome (Lawaetz et al. 1983), improved serum cholesterol and lipid profile (Brown et al. 1999), and diabetes prevention and control (Jenkins et al. 1977). Pectin is also supposed to contain some unique abilities that may prevent or treat the diseases/disorders viz., enteric diseases, cardiovascular diseases, obesity, cancer, etc. Recent clinical studies demonstrated that oral pectin supplementation to children and infants reduced acute intestinal infections and significantly slowed diarrhea (Rabbani et al. 2001; Triplehorn and Millard (2002). This clinical effect is supposed to be due to a reduction in pathogenic Gram-negative bacteria such as *Salmonella*, *Shigella*, *Klebsiella*, *Enterobacter*, *Citrobacter, and Proteus*. The above effect is supported by studies of Olano-Martin et al. (2002) who claimed that pectin was found to stimulate the growth of certain beneficial bacterial strains such as *Lactobacillus* and *Bifidobacteria* in vitro. These bacteria, typically known as "probiotics," are found to associate with the human health, also their concentrations depict a healthy microflora population. The consistency of fibrin is known to be a significant risk factor for cardiovascular diseases viz., atherosclerosis, heart disease, and stroke. Pectin has been found to increase permeability of fibrin and reduce the fibrin tensile strength in hyperlipidemic men (Veldman et al. 1999). Although the mechanism behind is still yet to be found. Perhaps, the potential ability of pectin is thought to be due to production of acetate. Pectin that primarily develops acetate in the colon and enters into the peripheral circulation is thought to alter and fibrin architecture. In the complicated field of cancer prevention, pectin may also have a potential role. Pectin has the ability to bind to galectin-3 and decrease tumor growth and cancerous cell migration in rats that fed on modified citrus pectin (Nangia-Makker et al. (2002).

8.3.5 Cellulose

Cellulose is a linear polymer of glucose monomers joined with beta 1,4 linkage and is the structural component of cell walls in plant kingdom. It shows resistance to the digestive enzymes particularly in small intestine. In addition, however, microbial fermentation in the large intestine may produce SCFA to a certain degree. It can be categorized into two groups, i.e., crystalline and amorphous. The crystalline component is made up of intra- and intermolecular non-covalent hydrogen bonds and provides water insolubility to the cellulose. Although various types of cellulose are present in the market for industrial purpose viz., modified celluloses such as powdered cellulose, hydroxypropylmethyl cellulose, and microcrystalline cellulose. Crystallization and hydrogen bonding are the main difference between the naturally occurring and modified celluloses. The cellulose derivative becomes water soluble on losing the crystallinity and breaking bonds (Takahashi et al. 2003). There are very few instances where an effort has been made to evaluate the effects of cellulose in human health. Therefore, studies should also be addressed in other organisms including the rat. Cellulose in the form of pills is available at market that have been claimed to decrease a person's caloric intake although no clinical research has been performed to evaluate the effect of above-mentioned claim on human beings. Other side, several studies that were conducted on different animal models viz., cats (Prola et al. 2006), dogs (Dobenecker and Kienzle 1998), and rats (Delorme and Wojcik 1982) have significantly established the correlation between cellulose consumption and decrease in energy intake. Several studies have measured the impact of cellulose in many different models on levels of blood glucose and insulin. The data, however, is highly contradictory and could rely on the subject, cellulose type, and other unknown factors. The consumption of natural cellulose was found to show a decrease in the postprandial glucose and insulin levels by using various animal models viz., the rat (Schwartz and Levine 1980), dog (Nelson et al. 1998), and cat (Nelson et al. 2000). Similar studies were also performed in humans (Schwartz et al. 1982) and pigs (Nunes and Malmlöf 1992) which demonstrated that natural cellulose did not cause any effect on these parameters while the studies using modified celluloses showed more consistent and significant results. The ability to reduce the blood glucose level with microcrystalline cellulose was studies on pig (Low et al. 1985) and rat (Takahashi et al. 2005). Methylcellulose had been claimed to show the similar effects in human beings. Lightowler and Henry (2009) reported a 37% decrease in postprandial glucose levels in healthy adults by applying 1% high-viscosity hydroxypro-PMC to mashed potatoes HV-HPMC. Davidson et al. (2007) advocated that 4 g of HV-HPCM in overweight individuals had a 35% acute reduction in postprandial blood glucose. Modified cellulose observed to show critical effect on lipid metabolism. In hypercholesterolemic adults who use 5 g/day HV-HPMC for one month, it has been observed a significant decrease in total and LDL cholesterol (Maki et al. 2000). It is noteworthy that HV-HPMC was able to reduce total and LDL cholesterol in subjects already taking statin medication. Modified celluloses can therefore be more beneficial than natural cellulose. Such modified celluloses function as soluble fibers, thereby increasing the GI tract's viscosity. The increased intestinal viscosity is therefore thought to slow the absorption of nutrients and increase the accumulation of bile acid.

8.3.6 Bran

Bran is the exterior layer of grain most commonly known to be the nucellar epidermis, seed coat, pericarp, and aleuron. Aleuron is made up of large wall-shaped cubic cells that are predominantly composed of cellulose. It is high in minerals, protein, and fat and low in starch. However, these nutrients are practically inaccessible in monogastric animals for digestion because of their thick cellulosic walls. The AACC describes oat bran as the food made by grinding clean oat, gratings, or rolling oats and by selecting the resulting oatmeal. The portion of oat bran is not more than 50% of the original starting material and has a total beta glucan content of at least 5.5% (db) and an overall dietarian fiber content of at least 16.0% at dry basis (AAAC 2010). Bran extracted from a wide range of grains has shown an effect on postprandial glucose levels, serum cholesterol, cancer of the colon and body mass. Although bran's efficiency can change due to the source, bran's general effect on the above parameters will be only assessed for purposes of this section. In a recent study on healthy adults, Qureshi et al. (2002) claimed the decrease in peak postprandial glucose levels by 35% by using 31 g of rye bran decreased in relation to the control. The coming outcome might be due to the presence of comparatively greater fraction of arabinoxylan in rye bran. Qureshi et al. (2002) observed in a study that subjects suffering type I and II diabetes mellitus decreased their fasting glucose levels by consuming 10 g of stabilized rice bran continuously for eight weeks. The results might be raised due to an increased intestinal viscosity, but was more likely due to decreased intake of carbohydrate. In a larger clinical study, Koh-Banerjee et al. (2004) backed this hypothesis by finding that body weight dropped by 0.80 lb for every 20 g/day rise in bran intake. This data remained important even after fat and protein intake change, daily activity, caloric intake, and weight of baseline. It should be noted. In a previous study, Zhang et al. (1994) observed that the excretion of fat, nitrogen, and energy by adult patients who eat bread rich in rye bran increased considerably. This study shows that bran did not slow absorption of nutrients but inhibited it in the small intestine. Besides the possible effect on absorption of carbohydrate metabolism, bran also has the same effect on lipids. Jensen et al. (2004) reported in a long-term clinical study that increased daily intake of brans significantly lowered the risk of coronary heart disease in healthy adult men. This is possibly because Qureshi et al. (2002) recorded that consumption of 10 g of bran for eight weeks and was found to reduce the serum totals of cholesterol, LDL, and triglycerides. The decrease in cholesterol levels might be due to an increase in the synthesis of bile acid. Andersson et al. (2002) found that oat bran is a metabolite in a bile acid synthetic that is oxidized from 7α-hydroxycholesterol, doubled the 7-α-hydroxy-4-cholesten-3-one (α-HC) serum concentration. A lower absorption of fat from the small bowel may lead to a reduction in the serum triglyceride levels (Zhang et al. 1994).

8.3.7 Resistant Starch

Higgins (2004) propounded the concept of resistant starch (RS) is that any starch not digested in the intestine. Without sacrificing mouth feel and palatability, resistant starch acts as soluble fiber. Therefore, resistant starch seeks to blend dietary fiber/full grain health benefits with the sensory experience of refined carbohydrates. Resistant starch has been categorized into four basic classes viz., type 1 resistant starch which is made up of starch granules surrounded by an indigestible plant matrix. Type

2 resistant starch exists in its natural form like in high amylose maize and an uncooked potato. Type 3 resistant starch is defined as the crystallized starches prepared by processes like cooking and cooling. Type 4 resistant starch is classified as a starch modified chemically by cross-linking, or transglycosylation and esterification, that not exist naturally. Haub et al. (2010) found that cross-linked type 4 (RS4) showed a greater decrease in blood glucose level as compared to type 2 (RS2). Several clinical human trials with resistant starch have been demonstrated a decreasing effect on glucose and insulin levels in the postprandial blood. However, because of variations in the nature and form of resistant starch used, it is difficult to fully understand these effects. Behall et al. (2006) advocated that the postprandial glucose and insulin level of women consuming 0.71, 2.57, and 5.06 g was significantly found lower when compared to control. Although the research findings did not maintain an equivalency between the treatments and control. It is therefore difficult to determine if glucose and insulin attenuation are due to resistant starch or due to low accessibility of carbohydrate in the meal. Reader et al. (2002) also found that 7.25 g of resistant starch through diet significantly reduced the blood glucose and insulin levels in healthy subjects. Al-Tamimi et al. (2009) removed these variables by controlling available carbohydrates and non-starch ingredients. It was claimed that the 30 g type 4 resistant starch supplementation has significantly reduced the postprandial blood glucose and insulin levels.

8.4 Therapeutic Importance of Dietary Fibers on Human Health

There are a number of advantages of dietary fibers for the sustainable human health. It brings the normalcy in bowl movement. Dietary fibers add weight and size to stool and softens the stool. The stool in bulk removes constipation through water absorption with dietary fibers; hence, a watery stool is transformed into solid stool. Diet containing high content of dietary fibers reduces the risk of developing hemorrhoids and small patches in colon of human. A number of studies have done to evaluate the preventive risk of dietary fibers in various types of cancer. The benefits of dietary fibers on human health have been mentioned in Table 8.2.

Soluble fiber found in beans, oats, flaxseeds, and oat bran helps to lower blood cholesterol levels by lowering low density lipoprotein “a bad cholesterol levels.” Several studies have shown that high fiber foods may have health benefits such as reducing blood pressure and inflammation. A diet with fiber helps to control blood sugar levels. Soluble fibers found in oats, beans, and citrus fruits slow down the absorption of sugar and help to improve blood sugar level. A healthy diet with insoluble fiber can also reduce the risk of type 2 diabetes. A handful of nuts or dried fruits are also being a healthy, high fiber snack. It is to take precaution that nuts and dried fruits are high in calories. Very good source of dietary fiber may be derived from by-products of fruit-vegetable processing industries. These by-products may be exploited for utilization of novel/uncommon source of dietary fiber including

Table 8.2 Importance of dietary fiber on human health

Functions of dietary fibers	Health benefits
Adds bulk to the stool	Helps in alleviating the constipation
Trapping carbohydrates by gel formation with water and slowing glucose absorption	Lowers the postprandial blood glucose level
Smoothens the enteric path with soothing properties of dietary fibers	Helps in regularity in the morning
Lowers the hypertension by controlling blood pressure	Poses preventive effects of type II diabetes, kidney disorders, and several types of neural diseases
Stimulates the intestinal production of short-chain fatty acids through fermentation by marinating the pH level	May have reducing effects to check the colorectal cancer
Reduces total serum and LDL cholesterol	Reduces the risk of cardiovascular diseases
Increases weight and size of stool	May have reducing effects on appetite

cereals, legumes, and seed by-products. Table 8.3 shows the dietary fiber and calories supplied by classical food and food products.

The food-borne fibers are suspected of degrading mineral absorption because of the in vitro bonding of the metal ions of the charged polysaccharide (such as pectins by their carboxylic groups). Charged polysaccharides do not affect the absorption of mineral and trace elements, but associated materials such as phytates can have a negative impact. The ability of various fibers to sequestrate and even to bind chemical bile acids was established as a possible mechanism for hypocholesterolemic action on certain dietary fibers which are rich in uronic acids and phenolic compounds. The environmental conditions of physical and chemical forms of dietary fibers and bile acid characteristics will affect fiber adsorption (Dongowski and Ehwald 1998; Thibault et al. 1992). Dietary fibers consist of water soluble and insoluble plant derived materials, which are digestibly inert, but are fermented by colonic bacteria to varying degrees. Dietary fibers got fermented in the small intestine by enteric microorganisms. Short-chain fatty acids are one of the most important components of the fermentation and also improve colon pH. The decreased pH creates an environment to prevent the growth of harmful bacteria (Topping and Clifton 2001; Macfarlane and Macfarlane 2003). The degree of fermentation is related to various physiological effects of dietary fibers. A rise in dietary fibers would increase the weight of stools and overcome and reduce the time of intestinal movement. Dietary fibers increase the fecal mass bulk by its ability to hold water so that the stools grow larger and moistest. Therefore, high-fiber diets help to avoid constipation and provide beneficial health effects. The rapid movement of the material decreases the transit cycle in the colon and thereby increases the re-absorption of water from the colon (Southgate and Penson 1983). Human study shows that dietary fibers given at doses of 20–26 g helps to normalize and enhance bowel function by reducing the incidence of constipation in older people (Dahl et al. 2003; Khaja et al. 2005). This combined to raise the fecal bulk by incorporating the

Table 8.3 Food source of dietary fiber

Types of food	Standard portion size	Respective calories	Dietary fiber content (g)[a]	Energy (calories/ 100 g)
Cooked winter squash	Half cup	38	2.9	37
Dates	Quarter cup	104	2.9	282
Pistachios, dry roasted	one ounce	161	2.8	567
Pecans, oil roasted	one ounce	203	2.7	715
Hazelnuts or filberts	one ounce	178	2.7	628
Peanuts, oil roasted	one ounce	170	2.7	599
Whole wheat paratha bread	one ounce	92	2.7	326
Quinoa, cooked	Half cup	111	2.6	120
Navy beans, cooked	Half cup	127	9.6	140
Adzuki beans, cooked	Half cup	147	8.4	128
Pinto beans, cooked	Half cup	122	7.7	143
Black beans, cooked	Half cup	114	7.5	132
Yellow beans, cooked	Half cup	127	9.2	144
Cranberry beans, cooked	Half cup	120	8.9	136
Lentils, cooked	Half cup	115	7.8	116
Mung beans, cooked	Half cup	106	7.7	130
Lima beans, cooked	Half cup	108	6.6	115
Cowpeas, cooked	Half cup	99	5.6	116
Soybeans, cooked	Half cup	149	5.2	173
Chia seeds, dried	One table spoon	58	4.1	486
Whole apple fruit	1 Medium	95	4.4	52
Sweet potato	1 Medium	103	3.8	90
Pumpkin, canned	Half cup	42	3.6	34
Avocado	Half cup	120	5.0	160
Figs, dried	Half cup	93	3.7	249
Popcorn, air popped	Three cups	93	3.5	387
Sunflower seed kernels, dry roasted	One Ounce	165	3.1	582
Banana	One medium	105	3.1	89
Dates	Quarter cup	104	2.9	282
Whole wheat spaghetti	Half cup	87	3.2	124
Collards, cooked	Half cup	32	3.8	33

Source: Dietary Guidlines-health.gov (2015–2020)

unfermentable residue. Propionate and butyrate fermentation results in higher concentrations than other soy-fiber substrate fermentation.

Dietary fiber is naturally present in plant-derived products viz., cereals, fruits, vegetables, and nuts. Dietary fibers vary from food to food in quantity and composition (Desmedt and Jacobs 2001). A fiber-rich diet is lower in energy density and often less fat, more voluminous and micronutrient based. This greater fraction of food takes longer to eat and its presence may bring a feeling of satiety in the stomach very quickly. However, this feeling of fullness exists for a short term (Rolls et al. 1999). The recommended daily dietary fibers for healthy adults should be 25 and 35 g for females and males, respectively. Various non-starch foods supply up to 20–35 g fiber per 100 g at dry basis, while others supply about 10 g per100 g at dry basis and fiber content of fruits and vegetables 1.5–2.5 g per 100 g of dry weight (Selvendran and Robertson 1994). The cereals have been found to be one of the main sources of dietary fiber Lambo et al. (2005) and sharing about 50% of the fiber intake in western countries although 30–40% of dietary fiber may come from vegetables, around 16% fiber from fruits, and the remaining 3% from other minor sources.

It was found that crude fibers values do not show the exact amount of the food which is accessible to human beings. In chemical treatments for the evaluation of synthetic fibers, greater loss of fiber is observed. Therefore, for evaluating the indigestible residue of human bodies, a basic in vitro process was used with pepsin and pancreatin. Pepsin and pancreatin were the source of optimal protein and starch digestion, which resulted in a minimal residue. The authors concluded that the determination of dietary fibers must be based on the use of food enzymes (Hellendoorn et al. 1975).

Southgate and Penson (1983) extracted both soluble and insoluble fibers for analysis that include lignin estimations. This uses calorimetric methods quite unreliable for the sugar analysis and does not exclude starch in certain foods altogether. Theander and Aman (1979) method may provide better technique for enumerating total, soluble and insoluble dietary fibers, and it does not exclude cellulose from the insoluble non-cellulose polysaccharide materials. Throughout the years in the United Kingdom, a variety of forms of research have been used for food safety labelling.

Englyst et al. (1982) have updated Southgate mining and have applied a gas-liquid chromatography for direct sugar calculation to significantly improve the specificity.

Two general approaches have been introduced to the recent research on dietary fiber methods such as enzymatic gravimetric and chemical methods.

The dietary fibers have shown to cause beneficial effects on the stool consistency and regularity. Perhaps, the dietary fibers help in laxation and add bulk in stool. One of the most sophisticated fibers, guar gum, is readily fermented by the microorganisms present in the small intestine (Salyers et al. 1977), helps in relieving the constipation, and improves bowel functioning in subjects (Takahashi et al. 1994). It has been observed the reduction in the incidence of diverticular disease by consuming dietary fiber consistently (Painter and Burkitt 1971) both in vegetarian and non-vegetarian individuals (Gear et al. 1979). The dietary fibers may have preventive effects in case of cancer of the large bowel by reducing the transit time, thus ultimately decreasing the time for synthesis and action of carcinogenic agents. In addition, the dietary fibers may have lowering effects on the concentration of fecal carcinogens thereby reducing the amount of carcinogens (Hill 1974; Burkitt 1975). The consumption of fiber-rich vegetables was inversely correlated to the frequency of large bowel cancer.

The preventive effects of dietary fibers on type II diabetes mellitus control and reduction in hyperinsulinism and sulfonylurea requirements was observed in both mild (Kiehm et al. 1976; Kay et al. 1981) and moderate (Albrink et al. 1979; Rivellese et al. 1980) effects on diabetic subjects on high fiber diets containing a normal (Miranda and Horwitz 1978; Simpson et al. 1979; Walker 1975) or higher (Kiehm et al. 1976; Simpson et al. 1979; Anderson and Ward 1979) fraction of carbohydrate. The high fiber content of fruits, vegetables, and legumes was proposed to be partly responsible for low plasma cholesterol levels (Anderson et al. 1973). Morris et al. (1977) found in a retrospective analysis an inverse association between cereal fiber intake and coronary disease death. Kay and Truswell (1977) stated that pectin, gum Arabic and guar gum also show a hypolipidic effect in human beings by lowering both total serum cholesterol and triglycerides (Takahashi et al. 1994). The physico-chemical properties of dietary fibers can be modified by treatments like enzymatic, chemical, mechanical, thermal, or thermo mechanical such as extrusion, cooked-extrusion, and instant decompression managed to boost functionality of dietary fibers (Guillon and Champ 2000). Mechanical energy has been proved to show profound effects on polysaccharides (Poutanen et al. 1998). On the other hand, grinding may affect the hydration properties such as kinetics of water uptake as a result of the increase in surface area. The thermal processes generally alter the fraction of soluble to insoluble fiber content. The combination of thermal and mechanical energy will significantly alter the dietary fibers, which may lead to new functional properties at any structural level.

The composition and availability of nutrients are changed by basic processes such as soaking and cooking. These often change the material of the plants cell walls that may be physiologically essential (Spiller 1986; Karla 1988). The thermal treatments including cooking, boiling increase the total dietary fibre content of wheat bran not because of new synthesis, but then, the production of heat-resistant fiber protein complexes quantified as nutritive fiber (Caprez et al. 1986).

The processing of vegetables viz., chick-pea, bean, lentil, etc. leads to the deterioration of food quality particularly reduce the total fiber content of the commodity. The common instances are the loss of total dietary fibers while cooking of lentils is probably due to loss in hemicelluloses fraction (Vidal-Valverda and Frias 1991; Vidal-Valverde et al. 1992). The thermal processing of kidney beans causes reduction in the total fiber content due to solubilization of polysaccharides. Varo et al. (1983) reported the effect of thermal treatments like extrusion cooking, boiling, and frying on the dietary fiber composition of vegetables and cereals; they advocated that processed potato was significantly found with comparatively greater fraction of water-insoluble dietary fibers and lower amount of starch as compared to control. However, insignificant changes were found in dietary fibers and starch content in food samples processed through extrusion. Herranz et al. (1983) advocated that boiling process improved the neutral detergent fiber (NDF), acid detergent fiber (ADF), and cellulose contents of the food samples. This improvement was found due to increase in hemicelluloses fraction, while no significant change was observed in lignin content of the samples. Consequently, the frying drastically reduced NDF, ADF, cellulose, and lignin content of the food samples, might be due to change in hemicelluloses fraction. The processing of raw carrots (*Daucus carota*) was found to increase the amount of non-starch polysaccharide per unit of dry weight. Although the cooking of canned carrots caused the increase in total and soluble non-starch polysaccharide per unit of dry weight (Penner and Kim 1991). The deep fat frying and microwave heating significantly increased the resistant starch (RS) and water-insoluble dietary fiber (Thed and Phillips 1995). They also claimed that domestic cooking methods did not affect the water-soluble dietary fibers.

The increase in water-insoluble dietary fiber might be due to starch in cooked potato that become indigestible by the amylopectin enzymes.

Camire et al. (1997) claimed that extrusion was found to increase the total dietary fiber, while it reduced the starch content of steam peels. They have also advocated the reduction in lignin while total dietary fiber remains unaffected in extruded abrasive peels. An effort was made to assess the effect of soaking on soluble, insoluble, and fiber content of several leguminous food viz., cow pea, dry pea, bengal gram, field bean, and green gram (Chopra et al. 2009). The food items were gone through soaking process with tap water (1:2 ratio) continuously for 12 h at room temperature (25 ± 5 °C). The dietary fiber content was significantly found to increase by 1.2–8.2% along with soluble dietary fiber. The texture, consistency, rheological properties, and organoleptic properties of the end products affected due to change in the dietary fiber (Guillon and Champ 2000). In the recent past, people have started to harvest the potential of agricultural waste for the value addition in processed food products such as soy hulls, oat hulls, wheat straw, peanut, fruits, and vegetable waste. The food technologists are continuously utilizing the food waste to produce a variety of value-added food products (Katz 1996). At major scale, various sources of dietary fibers are utilized to make value-added beneficial products by food and pharmaceutical industries. The deficiency of dietary fibers in the human diet leads to a number of non-communicable diseases viz., type II diabetes mellitus, polycystic ovary syndrome, colon cancer, etc. A number of fiber-fortified foods are available in the market viz., milk and meat products, bakery products such as integral breads and cookies. (Cho and Prosky 1999; Nelson et al. 2000). The incorporation of dietary fibers influenced the overall quality of the food product such as biochemical composition, cooking properties, textural and sensory characteristics of pasta, raw as well as cooked (Tudorica et al. 2002). The incorporation of dietary fibers lowers the glycemic index of food products. Hou et al. (1998) claimed that incorporation of gums to noodles made it firmer and rehydratable upon soaking and cooking. Nassar et al. (2008) has found that 15% of pulp and orange peel, being rich in dietary fibers could be incorporated in biscuits. It also improves the nutritional quality of biscuits without hampering the organoleptic attributes (Byrne 1997; Martin 1999). The substitution of wheat flour with defatted rice bran has shown to improve the quality without any technological defects in cookies. Consequently, the supplementation of cookies with rice bran has considerably improved the protein, dietary fibers, and mineral content of cookies.

Some of the polysaccharide have unique functional properties, which help in improving the food product quality, they make an impact in food products' quality by reducing syneresis, improving viscosity, emulsion formation, foam development, and stability in thawing and freezing. Some examples of these polysaccharides are cellulose, guar gums, alginates, pectin, inulin, etc.; their application is also found useful in cheese processing which helps to reduce its fat content without affecting sensory properties and texture of food.

Fibers sometimes create an adverse effect in the food consumed by babies less than 1 year. The baby food like pasta and bakery products when incorporated with dietary fibers create a loss in the availability of food products (Bustos et al. 2011). Fiber always has been useful in diet for adults as reported by food scientists. Some important sources of dietary fibers like bean flour, broken peas, and legumes when incorporated into a traditional pasta made from durum wheat semolina makes good impact on human health (Petitot et al. 2010).

Another factor causing functionality is the solubility of fiber in the diet. The viscous polysaccharide which is soluble reduces the digestion and absorption of nutrients in intestinal tract as it was reported by several research scientists. The structure of polysaccharide molecules when arranged in sequence of crystalline array makes it more stable in the solid state as compared to insoluble fibers (Guillon and Champ 2000).

Solubility is being increased by the presence of ionic group and beta glucan mixed with beta-1,4 linkage. Simplifying the oligosaccharide, disaccharides into monosaccharide units both in alpha and beta form also help to increase the solubility. Aravantinos-Zafiris et al. (1994) advocated that peel residue of orange is a good source of dietary fibers.

The extraction of pectin from orange peel and its residue when conducted with ethanol at 30° C for 30 min adding 5-times water. The content of fiber extraction was found 230 g/kg soluble and 626 g/kg insoluble dietary fibers on dry basis. The investigation was carried out by Fuentes-Alventosa et al. (2009) for preparation of fiber powders from asparagus. The by-product analysis, chemical composition and functional characteristics of powder were determined. When solvent extract and drying system was thoroughly studied for dietary fibers, it was found that treatments of water as a solvent produced highest dietary fiber while ethanol extracted gave the lowest fiber content.

Viscosity is a function of polysaccharide chain length, weight, and it increases the variety of fibers in solution. As viscosity is property of fluid which indicates the resistance to flow. Other factors like ionic strength, the shear condition, pH, temperature, and concentration of fiber are also influenced by changing these factors. The polysaccharides of long chain length such as guar gums and gums have the ability to bind considerably enough water and show high soluble fibers while relatively short-chain polymers have reduced viscosity such as guar gum and gums. Some polysaccharides found in fibers are associated with the substance such as phytates in their carboxyl group. It has the capability of the fibers to sequester metal ions chemically bind bile acid has been suggested as potential mechanism by which certain dietary fibers in uronic acid and phenolic compounds may have a hypocholesterolic action. Capacity of fiber for absorption may be influenced by the physical, chemical forms of fiber, nature of bile, and the essential condition, i.e., duration of exposure to pH (Dongowski and Ehwald 1998).

8.5 Conclusion

Since three past decades, awareness of dietary fiber for its health benefit has been well identified. Several food researchers and scientists demonstrated the application of dietary fiber in different types of food products. They explored the critical examination and utilization of dietary fibers through various investigations. Large number of sources of dietary fibers have been tapped. For example, dietary fiber from agro processing by-products, vegetables, fruits, soya been husk, and flour has been used in several meat products for the improvement in digestibility. There are several food products in the market which lacks in the dietary fiber and the consumer have been using these products since last three decades. The absence of dietary fiber in the diet leads to several non-communicable diseases such as intestinal disorder, coronary heart disease, diabetes, and obesity. Marketed product like biscuits, other bakery products, snack foods, pasta, noodles, and several meat products are deprived of dietary fiber. Such critical problems are being now solved by the expert food scientists such as the addition of fiber in Britannia biscuit named as Nutrichoice. At present, the author is working on dietary fiber incorporation in meat products. The dietary fiber sources are orange peel and apple pomace. These two waste materials/ by-products of food industry were first refined and given treatment to make them in edible condition.

References

AAAC. AACC adopts oat bran definition. Available online: http://www.aaccnet.org/news/pdfs/OatBran.pdf. Accessed on 12 October 2010

Abrams SA, Griffin IJ, Hawthorne KM, Liang L, Gunn SK, Darlington G, Ellis KJ (2005) A combination of prebiotic short-and long-chain inulin-type fructans enhances calcium absorption and bone mineralization in young adolescents. Am J Clin Nutr 82(2):471–476

Albrink MJ, Newman T, Davidson PC (1979) Effect of high-and low-fiber diets on plasma lipids and insulin. Am J Clin Nutr 32(7):1486–1491

Al-Tamimi EK, Seib PA, Snyder BS, Haub MD (2009) Consumption of cross-linked resistant starch (RS4 XL) on glucose and insulin responses in humans. J Nutr Metab 23:2010

Anderson JW, Ward K (1979) High-carbohydrate, high-fibre diets for insulin- treated men with diabetes mellitus. Am J Clin Nutr 32:2312–2321

Anderson JT, Grande F, Keys A (1973) Cholesterol-lowering diets. Experimental trials and literature review. J Am Diet Assoc 62(2):133–142

Andersson M, Ellegård L, Andersson H (2002) Oat bran stimulates bile acid synthesis within 8 h as measured by 7α-hydroxy-4-cholesten-3-one. Am J Clin Nutr 76(5):1111–1116

Aravantinos-Zafiris G, Oreopoulou V, Tzia C, Thomopoulos CD (1994) Fibre fraction from orange peel residues after pectin extraction. LWT—Food Sci Technol 27(5):468–471

Behall KM, Scholfield DJ, Hallfrisch JG, Liljeberg-Elmståhl HG (2006) Consumption of both resistant starch and beta glucan improves postprandial plasma glucose and insulin in women. Diab Care 29(5):976–981

Biorklund M, van Rees A, Mensink RP, Onning G (2005) Changes in serum lipids and postprandial glucose and insulin concentrations after consumption of beverages with beta-glucans from oats or barley: A randomised dose-controlled trial. Eur J Clin Nutr 59:1272–1281

Brown L, Rosner B, Willett WW, Sacks FM (1999) Cholesterol-lowering effects of dietary fiber: a meta-analysis. Am J Clin Nutr 69(1):30–42

Brownlee IA (2011) The physiological roles of dietary fiber. Food Hydrocoll 25:238–250

Burkitt DP (1975) Large-bowel cancer: an epidemiological jigsaw puzzle. J Natl Cancer Inst 54:3–6

Bustos MC, Perez GT, Leon AE (2011) Sensory and nutritional attributes of fiber-enriched pasta. J Food Sci Technol 44:1429–1434

Byrne M (1997) Low-fat with taste. Food Eng Int 22:36–41

Camire ME, Violette D, Dougherty MP, McLaughlin MA (1997) Potato peel dietary fiber composition: effects of peeling and extrusion cooking processes. J Agric Food Chem 45(4):1404–1408

Cani P, Joly E, Horsmans Y, Delzenne NM (2006) Oligofructose promotes satiety in healthy human: A pilot study. Eur J Clin Nutr 60:567–572

Caprez A, Arrigoni EV, Amadò R, Neukom H (1986) Influence of different types of thermal treatment on the chemical composition and physical properties of wheat bran. J Cereal Sci 4 (3):233–239

Cho SS, Prosky L (1999) Application of complex carbohydrates to food product fat mimetics. In: Cho SS, Prosky L, Dreher M (eds) Complex carbohydrates in foods, vol 1999. Marcel Dekker, New York, pp 411–430

Chopra H, Udipi SA, Ghugre P (2009) Dietary fibre content of selected legumes: varietal differences and effect of processing. J Food Sci Technol 46(3):266–268

Cugnet-Anceau C, Nazare JA, Biorklund M, Le Coquil E, Sassolas A, Sothier M, Holm J, Landin-Olsson M, Önning G, Laville M, Moulin P (2010) A controlled study of consumption of beta glucan-enriched soups for 2 months by type 2 diabetic free-living subjects. Br J Nutr 103 (3):422–428

Dahl WJ, Whiting SJ, Healey A, Zello GA, Hildebrandt SL (2003) Increased stool frequency occurs when finely processed pea hull fiber is added to usual foods consumed by elderly residents in long-term care. J Am Diet Assoc 103(9):1199–1202

Davidson MH, McDonald A (1998) Fiber: Forms and functions. Nutr Res 18:617–624

Davidson M, Witchger M, Dicklin M, Subbaiah P, Maki D, Witchger D (2007) Effects of high-fiber oat and wheat cereals on postprandial glucose and lipid responses in healthy men. Int J Vitam Nutr Res 77(5):347–356

Delorme CB, Wojcik J (1982) Interaction of dietary protein with cellulose in the adaptation to caloric dilution by weanling rats. J Nutr 112(1):21–28

Desmedt A, Jacobs H (2001) Soluble fibre. In: Guide to functional food ingredients. Food. RA Leatherhead, Surrey, pp 112–140

Dobenecker B, Kienzle E (1998) Interactions of cellulose content and diet composition with food intake and digestibility in dogs. J Nutr 128:2674S–2675S

Dongowski G, Ehwald R (1998) Properties of dietary preparations of the cellan-type. In: Guillon F et al (eds) Proceeding of the PROFIBRE Symposium, Functional properties of non-digestible carbohydrates. Imprimerie Parentheses, Nantes, pp 52–54

Doublier JL, Wood PJ (1995) Rheological properties of aqueous-solutions of (1→3) (1→4)-beta-D-glucan from oats (*Avena sativa* L.). Cereal Chem 72:335–340

Englyst H, Wiggins HS, Cummings JH (1982) Determination of the non-starch polysaccharides in plant foods by gas-liquid chromatography of constituent sugars as alditol acetates. Analyst 107:307–318

Fuentes-Alventosa JM, Rodríguez-Gutiérrez G, Jaramillo-Carmona S, Espejo-Calvo JA, Rodríguez-Arcos R, Fernández-Bolaños J, Guillén-Bejarano R, Jiménez-Araujo A (2009) Effect of extraction method on chemical composition and functional characteristics of high dietary fibre powders obtained from asparagus by-products. J Food Chem 113(2):665–671

Gajdošová A, Petruláková Z, Havrlentová M, Červená V, Hozová B, Šturdík E, Kogan G (2007) The content of water-soluble and water-insoluble β-D-glucans in selected oats and barley varieties. Carbohydr Polym 70(1):46–52
Gear JS, Fursdon P, Nolan DJ, Ware A, Mann JI, Brodribb AJ, Vessey MP (1979) Symptomless diverticular disease and intake of dietary fibre. Lancet 313(8115):511–514
Gibson GR, Roberfroid MB (1995) Dietary modulation of the human colonic microbiota: introducing the concept of prebiotics. J Nutr 125(6):1401–1412
Griffin IJ, Hicks PM, Heaney RP, Abrams SA (2003) Enriched chicory inulin increases calcium absorption mainly in girls with lower calcium absorption. Nutr Res 23:901–909
Guillon F, Champ M (2000) Structural and physical properties of dietary fibres, and consequences of processing on human physiology. Food Res Int 33(3-4):233–245
Haub MD, Hubach KL, Al-Tamimi EK, Ornelas S, Seib PA (2010) Different types of resistant starch elicit different glucose responses in humans. J Nutr Metab. https://doi.org/10.1155/2010/230501
Hellendoorn EW, Noordhoff MG, Slagman J (1975) Enzymatic determination of the indigestible residue (dietary fibre) content of human food. J Sci Food Agric 26(10):1461–1468
Herranz J, Vidal-Valverda C, Rojas-Hidalgo E (1983) Cellulose, hemicellulose and lignin content of raw and cooked processed vegetables. J Food Sci 48(1):274–275
Higgins JA (2004) Resistant starch: Metabolic effects and potential health benefits. J AOAC Int 87:761–768
Hill MJ (1974) Colon cancer: a disease of fibre depletion or of dietary excess? Digestion 11 (3-4):289–306
Hou G, Kruk M, Center WM (1998) Asian noodle technology. Tech Bull 20(12):1–10
Ide T, Okamatsu H, Sugano M (1978) Regulation by dietary fats of 3-hydroxy-3-methylglutaryl-coenzyme A reductase in rat liver. J Nutr 108(4):601–612
Jenkins DJ, Leeds AR, Gassull MA, Cochet B, Alberti KG (1977) Decrease in postprandial insulin and glucose concentrations by guar and pectin. Ann Intern Med 86(1):20–23
Jensen MK, Koh-Banerjee P, Hu FB, Franz M, Sampson L, Grønbæk M, Rimm EB (2004) Intakes of whole grains, bran, and germ and the risk of coronary heart disease in men. Am J Clin Nutr 80 (6):1492–1499
van der Kamp JW (2004) Dietary fiber – bio-active carbohydrates for food and feed. Wageningen, Wageningen
Karla R (1988) The physiological effects of dietary fiber-a review. Food Hydrocoll 2:1–18
Katz F (1996) Putting the function in functional food. Food Process 57(2):56–58
Kay RM, Truswell AS (1977) Effect of citrus pectin on blood lipids and fecal steroid excretion in man. Am J Clin Nutr 30:171–175
Kay RM, Grobin W, Track NS (1981) Diets rich in natural fibre improve carbohydrate tolerance in maturity-onset, non-insulin dependent diabetics. Diabetologia 20(1):18–21
Keogh GF, Cooper GJ, Mulvey TB, McArdle BH, Coles GD, Monro JA, Poppitt SD (2003) Randomized controlled crossover study of the effect of a highly beta glucan–enriched barley on cardiovascular disease risk factors in mildly hypercholesterolemic men. Am J Clin Nutr 78 (4):711–718
Khaja M, Thakur CS, Bharathan T, Baccash E, Goldenberg G (2005) 'Fiber 7'supplement as an alternative to laxatives in a nursing home. Gerodontology 22(2):106–108
Kiehm TG, Anderson JW, Ward K (1976) Beneficial effects of a high carbohydrate, high fiber diet on hyperglycemic diabetic men. Am J Clin Nutr 29(8):895–899
Koh-Banerjee P, Franz MV, Sampson L, Liu SM, Jacobs DR, Spiegelman D, Willett W, Rimm E (2004) Changes in whole-grain, bran, and cereal fiber consumption in relation to 8-y weight gain among men. Am J Clin Nutr 80:1237–1245
Lambo AM, Oste R, Nyman ME (2005) Dietary fibre in fermented oat and barley β- glucan rich concentrates. Food Chem 89:283–293

Lawaetz O, Blackburn AM, Bloom SR, Aritas Y, Ralphs DN (1983) Effect of pectin on gastric emptying and gut hormone release in the dumping syndrome. Scand J Gastroenterol 18 (3):327–336

Lia A, Hallmans G, Sandberg AS, Sundberg B, Aman P, Andersson H (1995) Oat beta-glucan increases bile acid excretion and a fiber-rich barley fraction increases cholesterol excretion in ileostomy subjects. Am J Clin Nutr 62:1245–1251

Lightowler HJ, Henry CJ (2009) Glycemic response of mashed potato containing high-viscosity hydroxypropylmethylcellulose. Nutr Res 29(8):551–557

Low AG, Pittman RJ, Elliott RJ (1985) Gastric emptying of barley-soya-bean diets in the pig: effects of feeding level, supplementary maize oil, sucrose or cellulose, and water intake. Br J Nutr 2:437–447

Lu ZX, Walker KZ, Muir JG, Mascara T, O'Dea K (2000) Arabinoxylan fiber, a byproduct of wheat flour processing, reduces the postprandial glucose response in normoglycemic subjects. Am J Clin Nutr 71:1123–1128

Lu ZX, Walker KZ, Muir JG, O'Dea K (2004) Arabinoxylan fibre improves metabolic control in people with Type II diabetes. Eur J Clin Nutr 58:621–628

Macfarlane S, Macfarlane GT (2003) Regulation of short-chain fatty acid production. Proc Nutr Soc 62:67–72

Maki KC, Davidson MH, Torri S, Ingram KA, O'Mullane J, Daggy BP, Albrecht HH (2000) High-molecular-weight hydroxypropylmethylcellulose taken with or between meals is hypocholesterolemic in adult men. J Nutr 130(7):1705–1710

Martin K (1999) Replacing fat, retaining taste. Int J Food Eng 24(3):57–58

Miranda PL, Horwitz DL (1978) High-fibre diets in the treatment of diabetes mellitus. Ann Intern Med 88:482–486

Morris JN, Marr JW, Clayton DG (1977) Diet and heart: a postscript. Br Med J 2(6098):1307–1314

Nangia-Makker P, Hogan V, Honjo Y, Baccarini S, Tait L, Bresalier R, Raz A (2002) Inhibition of human cancer cell growth and metastasis in nude mice by oral intake of modified citrus pectin. J Natl Cancer Inst 94(24):1854–1862

Nassar AG, AbdEl-Hamied AA, El-Naggar EA (2008) Effect of citrus by-products flour incorporation on chemical, rheological and organoleptic characteristics of biscuits. World J Agric Sci 4(5):612–616

Naumann E, VaN Rees AB, Önning G, Öste R, Wydra M, Mensink RP (2006) beta-Glucan incorporated into a fruit drink effectively lowers serum LDL-cholesterol concentrations. Am J Clin Nutr 83:601–605

Nazare JA, Normand S, Oste Triantafyllou A, Brac de la Perrière A, Desage M, Laville M (2009) Modulation of the postprandial phase by beta-glucan in overweight subjects: Effects on glucose and insulin kinetics. Mol Nutr Food Res 53:361–369

Nelson RW, Duesberg CA, Ford SL, Feldman EC, Davenport DJ, Kiernan C, Neal L (1998) Effect of dietary insoluble fiber on control of glycemia in dogs with naturally acquired diabetes mellitus. J Am Vet Med Assoc 212(3):380–386

Nelson RW, Scott-Moncrieff JC, Feldman EC, De Vries-Concannon SE, Kass PH, Davenport DJ, Kiernan CT, Neal LA (2000) Effect of dietary insoluble fiber on control of glycemia in cats with naturally acquired diabetes mellitus. J Am Vet Med Assoc 216(7):1082–1088

Nunes CS, Malmlöf K (1992) Effects of guar gum and cellulose on glucose absorption, hormonal release and hepatic metabolism in the pig. Br J Nutr 68(3):693–700

Olano-Martin E, Gibson GR, Rastall RA (2002) Comparison of the in vitro bifidogenic properties of pectins and pectic-oligosaccharides. J Appl Microbiol 93(3):505–511

Painter NS, Burkitt DP (1971) Diverticular disease of the colon: a deficiency disease of Western civilization. Br Med J 2(5759):450

Penner MH, Kim S (1991) Nonstarch polysaccharide fractions of raw, processed and cooked carrots. J Food Sci 56(6):1593–1596

Petitot M, Boyer L, Minier C, Micard V (2010) Fortification of pasta with split pea and faba bean flours: Pasta processing and quality evaluation. Food Res Int 43(2):634–641

Phillips GO, Cui SW (2011) AACC report: Definition of dietary fiber. http://www.aaccnet.org/news/pdfs/DFDef.pdf

Poutanen K, Suortti T, Aura AM, Liukkonen K, Autio K (1998) Influence of processing on the cereal dietary fibre complex: what do we know now? In: Guillon F (ed) Functional properties of non-digestible carbohydrates, profibre. Imprimerie Parentheses, Nantes, pp 66–70

Prola L, Dobenecker B, Kienzle E (2006) Interaction between dietary cellulose content and food intake in cats. J Nutr 136(7):1988S–1990S

Qureshi AA, Sami SA, Khan FA (2002) Effects of stabilized rice bran, its soluble and fiber fractions on blood glucose levels and serum lipid parameters in humans with diabetes mellitus Types I and II. J Nutr Biochem 13(3):175–187

Rabbani GH, Teka T, Zaman B, Majid N, Khatun M, Fuchs GJ (2001) Clinical studies in persistent diarrhea: dietary management with green banana or pectin in Bangladeshi children. Gastroenterology 121(3):554–560

Reader DM, O'Connell BS, Johnson ML, Franz M (2002) Glycemic and insulinemic response of subjects with type 2 diabetes after consumption of three energy bars. J Am Diet Assoc 102 (8):1139–1142

Ring SG, Selvendran RR (1980) Isolation and analysis of cell-wall material from beeswing wheat bran (Triticum aestivum). Phytochemistry 19:1723–1730

Rivellese A, Riccardi G, Giacco A, Pacioni D, Genovese S, Mattioli PL, Mancini M (1980) Effect of dietary fibre on glucose control and serum lipoproteins in diabetic patients. Lancet 2:447–449

Rolls BJ, Bell EA, Castellanos VH, Chow M, Pelkman CL, Thompson LU, Josse RG (1999) Energy density but not fat content of foods affected energy intake in lean and obese women. Am J Clin Nutr 69(5):863–871

Salyers AA, West SE, Vercellotti JR, Wilkins TD (1977) Fermentation of mucins and plant polysaccharides by anaerobic bacteria from the human colon. Appl Environ Microbiol 34 (5):529–533

Schwartz SE, Levine GD (1980) Effects of dietary fiber on intestinal glucose absorption and glucose tolerance in rats. Gastroenterology 79(5):833–836

Schwartz SE, Levine RA, Singh A, Scheidecker JR, Track NS (1982) Sustained pectin ingestion delays gastric emptying. Gastroenterology 83(4):812–817

Selvendran RR, Robertson JA (1994) Dietary fibre in foods: amount and type. In: Amado R, Barry JL (eds) Metabolic and physiological aspects of dietary fibre in food. Luxembourg, Commission of the European Communities, pp 11–20

Simpson RW, Mann JI, Eaton J, Carter RD, Hockaday TDR (1979) High-carbohydrate diets and insulin-dependent diabetes. Br Med J 2:523–525

Southgate DAT, Penson JM (1983) Testing the dietary fibre hypothesis. In: Brich CG, Parker KJ (eds) Dietary fibre. Applied Science, London, pp 1–19

Spiller GA (2001) Handbook of dietary fiber in human nutrition, 3rd edn. CRC, Boca Raton

Spiller GA (ed) (1986) CRC handbook of dietary fibre in human nutrition. CRC, Boca Raton, pp 285–286

Story JA, Furumoto EJ, Buhman KK (1997) Dietary fiber and bile acid metabolism—an update. In: Kritchevsky D, Bonfield C (eds) Dietary fiber in health and disease, Advances in experimental medicine and biology, vol 427. Springer, Boston, pp 259–266

Suortti T, Johansson L, Autio K (2000) Effect of heating and freezing on molecular weight of oat beta glucan. In: AACC Annual Meeting, Kansas, MO, USA, 5–9 November 2000

Takahashi H, Wako N, Okubo T, Ishihara N, Yamanaka J, Yamamoto T (1994) Influence of partially hydrolyzed guar gum on constipation in women. J Nutr Sci Vitaminol 40(3):251–259

Takahashi R, Hiraiwa Y, Nishinari K (2003) Cellulose and its derivatives. Foods and food ingredients. J Jpn 208:824–834

Takahashi T, Karita S, Ogawa N, Goto M (2005) Crystalline cellulose reduces plasma glucose concentrations and stimulates water absorption by increasing the digesta viscosity in rats. J Nutr 135(10):2405–2410

Tappy L (1995) Regulation of hepatic glucose production in healthy subjects and patients with non-insulin-dependent diabetes mellitus. Diabetes Metab 21:233–240

Theander O, Aman P (1979) The chemistry, morphology and analysis of dietary fibre component. In: Inglett G, Falkehag SI (eds) Dietary fibres: chemistry and nutrition. Academic, New York, pp 214–244

Thed ST, Phillips RD (1995) Changes of dietary fiber and starch composition of processed potato products during domestic cooking. Food Chem 52(3):301–304

Theuwissen E, Mensink RP (2007) Simultaneous intake of beta-glucan and plant stanol esters affects lipid metabolism in slightly hypercholesterolemic subjects. J Nutr 137:583–588

Thibault JF, Lahaye M, Guillon F (1992) Physiochemical properties of food plant cell walls. In: Schweizer E, Edwards C (eds) Dietary fibre, a component of food. Nutritional function in health and disease, ILSI human nutrition reviews. Springer, Berlin, pp 21–39

Topping DL, Clifton PM (2001) Short-chain fatty acids and human colonic function: roles of resistant starch and nonstarch polysaccharides. Physiol Rev 81(3):1031–1064

Törrönen R, Kansanen L, Uusitupa M, Hänninen O, Myllymäki O, Härkönen H, Mälkki Y (1992) Effects of an oat bran concentrate on serum lipids in free-living men with mild to moderate hypercholesterolaemia. Eur J Clin Nutr 46(9):621–627

Triplehorn C, Millard PS (2002) A rice-based diet with green banana or pectin reduced diarrhea in infants better than a rice-alone diet. ACP J Club 136:67

Tseng A, Zhao Y (2013) Wine grape pomace as antioxidant dietary fiber for enhancing nutritional value and improving storability of yoghurt and salad dressing. Food Chem 138:356–365

Tudorica CM, Kuri V, Brennan CS (2002) Nutritional and physicochemical characteristics of dietary fiber enriched pasta. J Agric Food Chem 50(2):347–356

Varo P, Laine R, Koivistoinen P (1983) Effect of heat treatment of dietary fiber: interlaboratory study. J Assoc Off Analyt Chem 66(4):933–938

Veldman FJ, Nair CH, Vorster HH, Vermaak WJ, Jerling JC, Oosthuizen W, Venter CS (1999) Possible mechanisms through which dietary pectin influences fibrin network architecture in hypercholesterolaemic subjects. Thromb Res 93(6):253–264

Vidal-Valverda C, Frias J (1991) Legume processing effects on dietary fiber components. J Food Sci 56(5):1350–1352

Vidal-Valverde C, Frias J, Esteban R (1992) Dietary fibre in processed lentils. J Food Sci 57:1161–1163

Walker ARP (1975) The epidemiological emergency of ischemic arterial diseases. Am Heart J 89:133–136

Wood PJ, Weisz J, Fedec P (1991) Potential for beta-glucan enrichment in brans derived from oat (*Avena sativa* L.) cultivars of different (1→3), (1→4)-beta-D-glucan concentrations. Cereal Chem 68:48–51

Yao N, Jannink JL, White PJ (2007) Molecular weight distribution of (1→3) (1→4)-β-glucan affects pasting properties of flour from oat lines with high and typical amounts of β-glucan. Cereal Chem 84(5):471–479

Zhang JX, Lundin E, Hallmans G, Adlercreutz H, Andersson H, Bosaeus I, Åman P, Stenling R, Dahlgren S (1994) Effect of rye bran on excretion of bile acids, cholesterol, nitrogen, and fat in human subjects with ileostomies. Am J Clin Nutr 59(2):389–394

Food Antioxidants: Functional Aspects and Preservation During Food Processing

9

Insha Zahoor and Farhana Mehraj Allai

Abstract

The food antioxidants have been a major focus of research in recent times. They were considered as magic bullets that could help to prevent the occurrence of different health issues. Recent studies have proved that antioxidants help in preventing or postponing the onset of some degenerative diseases. Although a variety of substances are found in foods, most research has been focused on vitamin E, vitamin C, and carotenoids. In order to understand the scientific knowledge of food antioxidants, it is important to know a little about the types of studies that researchers conduct while seeking to establish the possible link between food components and prevention of diseases. In the past, the only purpose of food preservation was to attain safety and extend the shelf life of food. However, this trend has changed and more attention is being given towards maintaining the nutrition along with improving the food functional properties. The retention of nutrients in the foods such as vitamins, the bioavailability of functional foods such as antioxidants and the preservation of other beneficial food components has become progressively important. To acquire high retention of heat-sensitive nutrients and functional components like antioxidants, various thermal and nonthermal processes are being performed.

Keywords

Antioxidants · Health benefits · Polyphenols · Functional food · Free radicals

I. Zahoor
Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

F. M. Allai (✉)
Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Department of Food Technology, Islamic University of Science and Technology, Awantipora, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_9

9.1 Introduction

Antioxidants play a crucial role in food systems as well as in the human body to alleviate oxidative processes. They have a long history of use in the food industry. Antioxidants are in themselves indispensable constituents of food. In simple terms, antioxidants are compounds that inhibit oxidation. However, the word "antioxidant" may mean different things to different people. In a broader perspective, antioxidant may be defined as "any substance that, when present at low concentrations compared to those of an oxidizable substrate, significantly delays or prevents oxidation of that substrate" (Halliwell 1990). Antioxidants play an important role in preventing the oxidation and have therefore attracted a considerable attention as food additives. They also have a positive influence on health of human as they can prevent the body against the damage of reactive oxygen species (ROS).

Antioxidants protect the food and consequently are helpful in maintaining human health. Earlier, antioxidants were primarily used to prevent oxidation and delay spoilage, but nowadays they are used because of a range of health benefits. Lipid autoxidation and subsequent generation of free radicals are natural processes occurring in biological systems including in food (Finley et al. 2011). The antioxidants are useful in retarding lipid peroxidation. This helps to retain flavor, texture, and color during the storage of the food. Antioxidants are used in a variety of foods. Use of antioxidants reduces rancidity, prevents the formation of toxic oxidation products in lipids, and permits the retention of nutritional quality and an enhancement in shelf life of foods. The improvement of oxidative stability of the foods containing lipids by the utilization of natural antioxidants has received a remarkable attention due to the global tendency to elude the utilization of synthetic food additives. Moreover, dietary antioxidants have been found to potentially improve human health by increasing antioxidant load of the body. Antioxidant supplements containing antioxidants like polyphenols, vitamin C, carotenoids, anthocyanins, and flavonoids find an immense demand in the current global market (Samaranayaka and Li-Chan 2011).

Both synthetic and natural antioxidants have been extensively used in food industry. There is a growing trend in the use of "natural" antioxidants for the preservation of food. Synthetic antioxidants are commonly replaced by the addition of natural oxidation inhibitors or by the use of ingredients that possess antioxidant activity. Plant-derived antioxidants such as vitamin C, vitamin E, and flavonoids are becoming important dietary antioxidant which helps to prevent against various diseases. Such natural antioxidants have already been commercialized as alternatives to synthetic antioxidants in food systems. However, natural antioxidants in foods are usually lost during food processing (Nicoli et al. 1997).

Butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) were extensively used artificial antioxidants due to their efficacy and high stability in various food systems. However, their use in food has decreased due to suspected adverse health effects as well as a result of a general rejection of synthetic food additives. Therefore, in past decades there has been an increasing awareness among consumers regarding the promotion and use of natural antioxidants instead of the synthetic ones. The safety concerns have resulted in intensifying interest in natural antioxidants. A wide range of antioxidants have been found to occur in plants and animals.

Many food industries have an adverse environmental impact due to the wastes they generate, and diminishing this concern has been an important subject. Antioxidants can be obtained from various food and agricultural wastes by employing different techniques. For instance, phenolic compounds can be regarded as added-value by-products and hence justifies their isolation from the industrial waste. Different by-products from the processing of fruits and vegetables have already been studied to find new sources of natural antioxidants (Suarez et al. 2009). Solvent extraction has been used for the recovery of phenols from plant tissues and is believed to be simple and suitable technique for extraction of antioxidants and subsequent use in the food industry.

This chapter discusses different food antioxidants, their health effects, and methods for their extraction from different sources. This chapter also covers applications of antioxidants in foods and effect of processing on them. The chapter is supposed to be helpful to researchers working on development or identification of novel types of plant antioxidant sources, and it is very likely that the increased consumption of plant foods will become the trend among the consumers over the globe. Commercialization of theses novel sources could be a subject of research. Moreover, there are various compounds that have been reported to possess antioxidant properties. But, their use in foods is limited due to their ambiguous influence on health. Research on toxicological studies on these antioxidants will help to identify the GRAS substances for permitted food use.

9.2 Types of Antioxidants

Antioxidants can generally be divided into two broad categories such as synthetic and natural. There is a growing trend in the use of "natural" antioxidants for the preservation of food. Synthetic antioxidants are commonly replaced by the addition of natural oxidation inhibitors or by the use of ingredients that possess antioxidant activity. Plant-derived antioxidants such as vitamin C, vitamin E, and flavonoids are becoming important dietary antioxidant which helps to prevent against various diseases. Such natural antioxidants have already been commercialized as alternatives to synthetic antioxidants in food systems. However, natural antioxidants in foods are usually lost during food processing (Cao et al. 1998).

9.2.1 Polyphenols

Polyphenols are micronutrients in our diet, and their role in the prevention of degenerative diseases such as cancer and cardiovascular diseases is arising. Several thousand molecules having a polyphenol structure have been found in higher plants, and several hundred are identified in edible plants. Caffeic acid is most plentiful phenolic acid and indicates between 75 and 100% of the total hydroxycinnamic acid content of most fruit (Crespy et al. 2002). Ferulic acid is the common phenolic acid found in cereal grains. The most common sources of dietary polyphenols are fruits such as apples, grapefruit juice, oranges, and cranberries (Haminiuk et al. 2012); vegetables such as onions, spinach, broccoli, and green olives (Mattila et al. 2006); fats such as dark chocolate and olive oil (Vasta and Priolo 2006); beverages such as tea, coffee, and red wine (Mattila et al. 2006); spices such as saffron, dried rosemary, cloves, and cumin (Shahidi and Ambigaipalan 2015).

9.2.2 Flavonoids

Flavonoids is the subclass of polyphenols and is predominantly found in potatoes, tomatoes, wheat, peaches, almond, and red berries. It is the main class of antioxidants responsible for plant pigment and is abundantly present in nature. Flavonoids are further divided into several classes: flavanones, flavones, flavonols, flavanols, isoflavones, and anthocyanidins. Flavonols make up the most essential group of flavonoids in foods. Quercetin and kaempferol are the main representatives of flavonoids and is found in grains, tomatoes, honey, orange juice, drumstick, etc. Flavonols are more common in fruits and vegetables than flavones. Flavanones are also present in aromatic plants like mint but in less quantity than citrus fruit. Flavanols exists in two forms—catechins known as monomeric form and proanthocyanidins known as polymer form (Liu 2007). Catechin and epicatechin are the major flavanols found in fruits, whereas gallocatechin, epigallocatechin gallate, and epigallocatechin are present in leguminous plants, tea, and grapes.

9.2.3 Anthocyanin

Anthocyanin is the subcategory and largest group of flavonoids found in purple carrots, tomatoes, red wine, cereals, certain leafy root vegetable, pomegranate, and berries. It is a class of natural bioactive compounds present in beverage and food material. Anthocyanins are one of the pigment groups dissolved in the sap of epidermal tissues of fruits, vegetables, and flowers to which they impart purple, blue, pink, or red color. Moreover, anthocyanidins (aglycone) form of anthocyanin is the most unstable state, while as it is present in plants and are resistant to oxidation conditions, light, solvents, ascorbic acid, enzymes, and pH that are likely to deteriorate them. Although, when complexes are formed with other flavonoids, anthocyanins become more stable.

9.2.4 Carotenoids

Carotenoids are a fat-soluble provitamin present in fruits and vegetables. It is another main class of antioxidants in fruits and vegetables after polyphenols. They are efficient antioxidants that help in the prevention of several health diseases like metabolic disorders, cancer, and CVD. Carotenoids scavenge peroxyl radicals and molecular singlet oxygen. In human beings, carotenoids play an important role in defense mechanism. The antioxidant properties of carotenoids are of having prime significance to human health as they are known to quench singlet oxygen species as well as to protect against several chronic disorders (Cvetkovic et al. 2013).

9.2.5 Vitamin C

Fruits and vegetables contain vitamins and essential micro- and macronutrients. Among all vitamin C is the most unique vitamin because of the several potential reasons. It is water-soluble bioactive compound commonly present in citrus fruits and vegetables like lemons, tomatoes, and oranges. It has a function of redox buffer which reduces and neutralizes the reactive oxygen species. Vitamin C has been reported to be an effective scavenger against reactive species, nitrogen oxide, and oxygen species like hydrogen peroxide, superoxide radical ion, and singlet reactive oxygen species. This application of ascorbic acid makes it vital for the prevention of cellular substances against free radical-induced damage. Moreover, ascorbic acid is effective in regenerating the phytochemical compound form of tocopherol (vitamin E) by reducing tocopheroxyl radical (Padayatty et al. 2003).

9.3 Health Benefits of Antioxidants

9.3.1 Antioxidants

In plants, several phenolic compounds are present which may have antioxidant property; these compounds inhibit the free radicals and other biomolecules which react to cause serious damage to human health (Chang et al. 2016). Polyphenols, vitamin E, and flavonoids are the three main classes of phenolic compounds with antioxidant activity. Grape skin and red wine contain resveratrol, a phenolic compound that also have antioxidant effect.

9.3.2 Prevention of Cancer

Bioactive compounds are known to prevent cancerous-like diseases. Flavonoids belong to a large group of phenolic compounds that occurs in plant products and other substances containing anthocyanins that may have anticancer effect (Smeriglio et al. 2016), e.g., green tea contains epigallocatechin-3 gallate, a phenolic compound that are believed to be a cancer chemopreventive.

9.3.2.1 Anti-Tumor Properties

Carotenoids are the most potent antioxidants that prevent cancer. It has the ability to quench singlet oxygen and scavenge other reactive oxygen species. Carotenoids and other metabolites play an important role in protecting several disorders related to ROS like CVD, disorder related to eye, neurological disorder, and various types of cancerous diseases. Carotenoids contain a group of metabolites known as acetylenics to reduce the development of tumor and also support the immune system (Zhou and Raffoul 2012). The combination of these characteristics has been so influencing for fighting against immune-related infections and other cytotoxic effects related to cancer.

9.3.3 Health and Skin

Carotenoid is natural antioxidant with potential application in food industry. Carotenoids, beta carotene, and beta cryptoxanthin have bioactive characteristic that protects the tissue, cells, and skin against diseases and environmental toxins. Researchers reported that non-provitamin A like astaxanthin, lutein, and zeaxanthin also have beneficial photochemical effects. Bioactive compounds may protect the human body cells from toxins generated from smoking of cigarette and other contaminations produced by environment. Free radical synthesis can enhance bad cholesterol or LDL which leads to the risk of CVD. Vitamin A carotenoids from fresh fruits and vegetables are recommended to have numerous health benefits that protect the skin and other harmful diseases (Fiedor and Burda 2014).

9.3.4 Anti-Inflammatory Effects

Flavonols are the most abundant class present in chocolate, cocoa, and *Vitis vinifera* grape berry skin that may inhibit the inflammation of arteries. The main dietary flavonols are rutin, quercetin, isorhamnetin, and kaempferol. Quercetin is the most important flavonols present in fruits and vegetables. Molecules that are binded together with one another cause building up of plaque in the arteries that may lead to the risk of cardiovascular disease, especially hardening of blood vessels and atherosclerosis. Organosulfur-derived compounds have also been reported to reduce the enzymes responsible for inflammation, and also decrease the synthesis of inducible nitric oxide synthase (iNOS) in white blood cell (Sandur et al. 2007).

9.3.5 Inhibition of Cholesterol Synthesis

Organosulfur compounds like garlic and garlic-derived substances have been reported to reduce the production of liver cell cholesterol by hepatocytes. Ajoene and S-allylcysteine are the garlic-derived compounds to retard 3-hydroxy-3-methyl-glutaryl-coenzyme A reductase (HMG-CoA reductase). Garlic-derived substances may also retard the other enzyme pathway like sterol 4-α-methyl oxidase (Sandur et al. 2007) that are responsible for the inhibition of synthesis of cholesterol.

9.4 Extraction of Antioxidants from Plant Sources

Extraction is a separation technique that are used to extract bioactive compounds from plant source using specific solvents by adopting standard method (Handa et al. 2008). Several different methods and procedures have been developed for the analysis of bioactive compounds. These techniques involve the estimation of total antioxidant capacity and the individual quantification and detection of different antioxidant substances. The main aim of this extraction technique is to separate the solute molecules from the by-products of plant for performing the efficient extraction method. The extraction efficiency is based on concentration and type of solvent used, time, temperature, and pH of extraction method (Xu et al. 2017). Among these factors, the choice of solvent is one of the most influential parameter. Several different solvents have been used for the method of extraction of bioactive compounds from plant source. The selection and choice of solvent depend upon the polarity and chemical nature of bioactive compounds to be separated (Van Tang et al. 2016). The extraction of antioxidant compounds from plant is mainly influenced by the processes that are carried out to extract liquid–solid process. As each and every plant has a unique feature in terms of their composition and structure, the interaction of material solvent is unpredictable when combined with solvents (González-Montelongo et al. 2010). There are several different techniques that are used to extract bioactive compounds efficiently from plant sources, and these methods are discussed below with their applications.

9.4.1 Extraction of Bioactive Compounds with Solvents

The solvent extraction method is used to separate the desired compound (solute) from the given solid food by using different solvents like hexane, methanol, ethanol, and ethyl alcohol. An ideal solvent should possess following properties (Oroian and Escriche 2015; Selvamuthukumaran and Shi 2017):

- It should be highly selective.
- The capacity to extract solute molecules should be high.
- It should be chemically stable, i.e., irreversible reactions do not take place between the contacting components.
- Specific compounds should be dissolved to a large extent.
- Polarity of solvent.
- Molecular affinity between solute and chosen solvent.

Solvents used for the separation of bioactive compounds from plant material depends on the polarity of solute. If the polarity of solvent is similar to that of

Table 9.1 Applications of the commonly used solvents for the extraction of antioxidant compounds from plant source

Source	Compounds Extracted	Solvent Used	Reference
Peel of egg plant	Anthocyanins	70% methanol	Boulekbache-Makhlouf et al. (2013)
	Total phenolics, flavonoids, and tannins	70% acetone	
Olives	Total phenolic compounds, hydroxycinnamic acids, and flavonols	70 ml/100 ml ethanol extracts highest yields	Tsakona et al. (2012)
Tomato	Lycopene	40% acetone in ethyl acetate	Strati and Oreopoulou (2011)
Carrot	Carotenoid	Sunflower oil	Li et al. (2013)
Red cabbage	Anthocyanins	1% (v/v) HCl in methanol	Chandrasekhar et al. (2012)
Tea	Flavonoids	Ethanol	Wang and Helliwell (2001)
Limnophila aromatic (spice)	Total phenolic and flavonoid content	Mixture of 50% methanol, 75% ethanol, 100% acetone in water	Do et al. (2014)

targeted compound (solute), then solute gets dissolved properly but for the use of multiple solvents, sequential order should be followed from low polar to high polar, in order to limit the amount of analogous components in the desired yield and also eliminate the interference of water or other solvents at the same time.

Ethanol is one of the most commonly used solvents for the extraction of antioxidant compounds because of its properties like reusable, nontoxic, and cheap (Chew et al. 2011). Different concentrations of aqueous ethanol were used for the extraction of phenols by fractionating phenolic compounds on the basis of their polarity (Durling et al. 2007). The applications of the commonly used solvents for the extraction of antioxidant compounds from some foods are given in Table 9.1.

9.4.2 Microwave-Assisted Extraction

Microwave-assisted extraction (MAE) is considered to be the novel and most popular technique for the separation of bioactive compounds from a wide range of materials. This method is significantly used as it reduces the solvent volume and extraction time by using microwave energy and thus increases the efficiency of extraction process (Selvamuthukumaran and Shi 2017). Microwave is an electromagnetic radiation having frequency range from 300 MHz to 300 GHz that can deliver their energy to the food matrix and solvent. This energy is then absorbed by the polar molecules present inside the plant, i.e., the principle of MAE is based on its direct effect on polar molecules. The extraction is done under controlled temperature and pressure. The localized pressure, temperature, and mechanical stress caused due

Table 9.2 Applications of the microwave-assisted extraction of antioxidant compounds from plant source

Source	Compounds extracted	Method	Reference
Myrtus communis L. leaves	Total phenolics, flavonoids, and tannins	MAE	Dahmoune et al. (2015).
Onion	Flavonoids	SFME	Zill-e-Huma et al. (2009)
Citrus deliciosa T. leaves	Phenolic content	SFME	Perino-Issartier et al. (2011)
Silybummarianum	Flavono Lignan-Silybinin	MAE	Dhobi et al. (2009)
Grape skin	Anthocyanins	MAE	Liazid et al. (2011)
Milk thistle seeds	Silymarin	MAE	Zheng et al. (2009)
Chinese tea	Phenolic compounds	MAE	Tsubaki et al. (2000)
Pomegranate seed residue	Phenolic compounds	SWE	He et al. (2012)
Ginger	Essential oils	MHG	Asofiei et al. (2017)

SFME solvent-free microwave extraction, *MAE* microwave-assisted extraction, *SWE* subcritical water extraction, *MHG* microwave hydrodiffusion and gravity

to microwave process can significantly damage the cell wall, ruptures it and releases the bioactive (target) compounds (Florez et al. 2015). During the cell disruption process, the mass transfer of extraction process enhances due to higher penetration capacity. MAE method has been used for the separation of phytochemical compounds from plant material with or without the use of addition of solvent material (Tsubaki et al. 2010) (Table 9.2). The factors that influence the MAE are solvent selection, time and temperature of irradiation, ratio of solvent to material, plant matrix characteristics, and microwave power (Pasrija and Anandharamakrishnan 2015).

Advantages of MAE (Cravottoa et al. 2008) are as follows:

- Fast heating for separation of antioxidant compounds from sample matrix.
- Use of reduced size of equipment.
- Extraction process is rapid.
- Decreased temperature gradient.
- Enhances the yield extract.
- Better recovery.

The mechanism of MAE has three basic steps that involve (Alupului et al. 2012) the following:

- Under increased pressure and temperature, the separation of solute compounds from active sites of plant matrix takes place.
- Diffusion of solvent across plant matrix.
- Release of solute molecules from plant matrix to solvent.

MAE has several different types of extraction methods:

1. *Subcritical water extraction (SWE)*: This method is also known as pressurized water. It is a powerful technique where water is heated between 100 and 347 °C under critical pressure below than 22 MPa to maintain liquid state (Karakama 2011). It is significantly used as it enhances the extract quality and increases the extraction volume of phytochemical compounds from a wide range of natural sources (Saravana et al. 2018). SWE has several benefits like faster, cost economic, cleaner, greater sustainability, decreases polarity, quality and safety of products (Lee et al. 2018). In this technique, water is used as a solvent for the phenolic extraction by using dielectric constant with increase in temperature. As the temperature enhances, there is a systematic reduction in surface tension and viscosity, permittivity, and increase in rate of diffusion.
2. *Solvent-free microwave extraction (SFME)*: This type of microwave extraction is used in combination with microwave heating and dry distillation under atmospheric pressure without addition of water or any other solvent (Michel et al. 2011), e.g., extraction of essential oils from natural and aromatic herbs and spices.
3. *Microwave hydrodiffusion and gravity (MHG)*: It is a process technology used for the separation of essential oils under atmospheric pressure without using any solvent. It is cost-effective, efficient, and friendly technique.

9.4.3 Enzymes-Assisted Extraction

Enzyme-assisted extraction method uses specific enzymes to rupture the cell wall of plant source in order to increase the extraction yield. A wide range of enzymes like pectinases, cellulases, α-amylase, β-glucosidase, and hemicellulases (Table 9.3) are often used to disrupt the structure of plant cell wall integrity, thereby increasing the separation of phytochemical compounds from plant matrix. These enzymes are derived from bacteria, fungi, fruit/vegetable extract, and animal organs (Cheng et al. 2015). The yield and efficiency extraction depends on the type of enzyme used, pH, concentration, time and temperature of incubation, particle size, and ratio of liquid to solid (Liu et al. 2016).

9.4.4 Ultrasound-Assisted Extraction (UAE)

UAE is a special type of sound wave technique that have wide range of applications in food processing sector to extract antioxidant compounds from the plant matrix (Williams et al. 2004) (Table 9.4). The frequency of sound wave used for this technique is beyond human hearing and is in the range of 20 KHz to 100 MHz. Waves greater than 20 KHz frequency is used to rupture the cell wall of plant source, i.e., it passes through a medium by forming expansion and compression that helps to increase the penetration of solvent material into the cell and thus obtains maximum extraction yield. It is one of the commonly used extraction methods because of the

Table 9.3 Applications of the enzyme-assisted extraction of antioxidant compounds from plant source

Source	Compounds extracted	Enzymes	Reference
Grape pomace	Phenolic acids, anthocyanin, and non-anthocyanin flavonoids	2:1 ratio of pectinolytic and cellulolytic	Maier et al. (2008)
Watermelon rind	Phenolic compounds	Mixture of pectinases, protease, α-amylase, β-glucosidase	Mushtaq et al. (2015)
Cauliflower (*Brassica oleracea*)	Polyphenols	Viscozyme L-0.2% and 0.5% for rapidase	Nguyen et al. (2014)
Grape waste	Phenolic compounds	Celluclast, novoferm, and pectinex	Gomez-Garcia et al. (2012)
Citrus peel (yen ben lemon, grapefruit, mandarin, and orange)	Total phenolic content	Celluzyme MX	Li et al. (2006)
Water melon (*Citrullus lanatus*) rind	Lycopene	Cellulase and pectinase	Mushtaq et al. (2015)

use of common equipments like ultrasonic water bath and ultrasonic probe system. UAE is a simple, faster, efficient, cost-effective, use of less solvent, less extraction time (5–60 min) and effective method. Moreover, in ultrasonic extraction technique, the chemical involvement is not there, thus prevents the target compounds from chemical degradation (Chemat and Khan 2011).

The separation mechanism by ultrasound process consists of two major types of physical phenomena: cell wall diffusion and after rupture of wall, the contents of cell were rinsed (Selvamuthukumaran and Shi 2017). Effective and efficient extraction of ultrasound technique depends on the particle size of sample, moisture content, solvent, milling degree, pressure, temperature, frequency, and sonication time. During extraction process, the ultrasound energy facilitates faster transfer of energy, more effective mixing, decreased temperature gradient, reduced extraction temperature, enhanced yield, reduced equipment size, response of extraction control is faster and it eliminates error or process steps (Chemat et al. 2008).

9.4.5 Supercritical Fluid Extraction (SFE)

Supercritical fluid extraction (SFE) technique as a sustainable green technology that has attracted wide scientific interests. It has been extensively and successfully used in many sectors since the past decades like polymer, food industry, biomaterial processing, and pharmaceutical (Zougagh et al. 2004). Supercritical state is unlike normal solvent extraction, in which the temperature (T_C) and pressure (P_C) are subjected to over its critical point and solvent can be changed into the state of

Table 9.4 Applications of the ultrasound-assisted extraction of antioxidant compounds from plant source

Source	Compounds extracted	Processing device	Reference
Mulberry pulp	Anthocyanins and phenolic compounds	10–70 °C temperature, 50–100% methanol concentration, 30–70% ultrasound amplitude, 0.2–0.7 s cycle, 3–7 pH solvent, 10:15–20:15 solvent–solid ratio	Espada-Bellido et al. (2017)
Strawberries	Phenolic compounds—rutin, naringin, allagic acid, quercetin, and kaempferol	0.8 s–30 s duty cycle, 50% output amplitude than nominal amplitude of the converter, 100 W power.	Herrera and Luque-de-Castro (2004)
Cabernet franc grapes	Anthocyanins and tannins	24 KHz for 5–15 min	El-Darra et al. (2013)
Orange peel	Total phenolic content and flavanone concentration—naringin and hesperidin	40 °C temperature, 150 W sonication power, and 4:1 ethanol: Water ratio	Khan et al. (2010)
Apple pomace	Polyphenols	25 s extraction time, 1000 W power, and 5:1 liquid to solid ratio	He et al. (2015)
Black potato peel (*Coleus tuberosus*)	Oleanolic acid and ursolic acid	60 °C temperature for 60 m, 100 W power, 42 kHz, and 1:75 solid to solvent ratio	Hadiyanto et al. (2014)
Tomato pomace	Lycopene and β-carotene	Temperature = 25 °C for 10 min, 20 kHz and 50:50 ratio of hexane: Ethanol	Luengo et al. (2014)
Grape seeds	Anthocyanins, antioxidants, and phenols	Temperature = 33–67 °C for 16–34 min, 40 kHz, 250 W and solvent: Ethanol ratio, 33–67% of ethanol concentration	Ghafoor et al. (2009)

supercritical fluid. Supercritical fluid increases the properties of the material to be transported so that it can easily diffuses through the solid material and thus gives high extraction yield (Da Silva et al. 2016). SFE system has basically a mobile phase tank, carbon dioxide, pump to pressurize gas and co-solvent vessel, oven that have extraction vessel, controller inside the system to maintain high pressure and a trapping vessel. Super critical fluid extraction utilizes the antioxidant properties of supercritical fluids to separate the target material from various matrices (Table 9.5). The extraction efficiency of phytochemical compounds from plant matrix by SFE depends on several factors like moisture content of sample, particle size, operating pressure, time and temperature of extraction, solvent: feed ratio, quantity of modifier, and solvent and CO_2 flow rate (Ibanez et al. 2012).

SFE has generally two main steps: supercritical solvent extracts the soluble compounds from the plant source and then these extracted compounds are again separated from the supercritical solvent with the help of increasing temperature, reducing pressure or both (Pereira et al. 2016). Carbon dioxide is used to improve the efficiency of extraction process of polar compounds by adding polar organic

Table 9.5 Applications of the supercritical fluid extraction for the separation of antioxidant compounds from plant source

Source	Compounds extracted	Processing unit	Reference
Citrus fruit	Higher extraction yield of naringin-flavonoids	Supercritical CO_2 modified with 15% wt ethanol	Giannuzzo et al. (2003)
Grape seeds	Polyphenols and procyanidins	SFE with methanol as modifier	Khorassani and Taylor (2004)
	79% of catechins and epicatechin	40% of methanol modified CO_2	
Grape seeds	Phenolic compounds	Alcohol and CO_2	Murga et al. (2000)
Ripe tomatoes	Lycopene	SFE-CO_2 with ethanol	Cadoni et al. (2000)
Merlot and Syrah grape pomace	Polyphenols—gallic acid, epicatechin, p-OH benzoic acid, and vanillic acid	Supercritical CO_2 with CO-solvent at a temperature of 50 and 60 °C and pressure up to 300 bar.	Oliveira et al. (2013)
Jamun fruits	Anthocyanin and phenolic compounds	SFE-CO_2 with ethanol	Maran et al. (2014)
Persimmon (*Diospyros kaki* L.),	Carotenoids, xanthophylls, zeaxanthin, and lutein	Pressure 300 bar, temperature 60 °C, and 3 mL/min CO_2 flow rate	Zaghdoudi et al. (2016)
Rosemary	Polyphenols	Supercritical CO_2	Visentin et al. (2012)
Elderberry pomace	Polar compounds	Enhanced solvent extraction technique with ethanol as a modifier	Serra et al. (2010) Veggi et al. (2011)

solvents in small quantity as a modifier. The main drawback of CO_2 is that it cannot separate high-molecular-weight compounds like anthocyanins as it is non-polar and lipophilic in nature. The low polarity of CO_2 makes it suitable for the extraction of fat, lipid, and non-polar compounds but non-ideal for polar substances. Chemical modifier is used to eliminate the drawback of low polarity of CO_2 (Ghafoor et al. 2010), e.g., 0.5 ml of dichloromethane can increase the extraction process. Another way to overcome this limitation is the use of enhanced solvent extraction (ESE). This technique is used for the extraction of polar compounds by using organic solvents, water, and CO_2 at a temperature of 40–200 °C and a pressure of 3.3 and 20.3 MPa (Adil et al. 2008).

9.5 Effect of Processing on Antioxidant Activity of Food

Antioxidants are phytochemical non-nutrient compounds found in plant food such as grains, vegetables, fruits, tea, and other plant foods that have an ability to scavenge the free radicals and are associated with numerous health benefits (Liu 2004). These bioactive compounds result in having a novel perception concerning the potential of healthy and functional diet that helps in protecting against the chronic diseases. Nutritional parameters are significantly considered to be important for the human health. Consumption of diet rich in phytochemical compounds has been studied to prevent the further growth of abnormal cells in the chronic diseases like cancer and tumor (Song et al. 2010). It also maintains the lower risk of breast, colon, lung, esophageal, bladder, and stomach cancer (Nayak et al. 2015). However, some food items need to be processed before taking it to have better metabolism and digestion of food.

Antioxidants play a vital role in the improvement of human health and in physiological systems of plant (Shahidi and Ho 2005). In food system, phytochemicals vary their functionality and stability in human body that depends on the position in food matrix, presence of other bioactive compounds, and association of the molecules present in the food (Hannum 2004). The main concern for the utilization of bioactive compounds during food preparation is to maintain the freshness and inhibit the rancidity and browning reactions in oils or fats and other foods which are prone to oxidative rancidity or deterioration. Generally, processing of food is considered to be the major parameter on alteration of natural bioactive compounds, which may influence the antioxidant activity in foods. Several changes that occur during processing of processed food includes change in composition, sensory, nutrition, appearance, flavor, and texture of food items. Therefore, there is a need of an hour to assess the changes that take place in antioxidant activity on processing/cooking.

In fruits and vegetables, antioxidants either exist in bound or free form. These bioactive compounds are bounded within the cell membrane of plant. During processing, heating damages the cell membrane and thus releases the bounded form of phytochemical compounds that have maximum bioaccessibility (Leong and Oey 2012). The above literature suggested that the bioactive compounds present in either of forms can contribute towards the total antioxidant capacity of fruits and vegetables. Processing of food is primarily done to inactive the microorganism causing diseases and to concentrate the processed food by reducing its moisture content or to remove the skin of fruit and vegetable by soften the outer tissue. Foods rich in phytochemicals like phenolics, carotenoids, xanthophylls, and vitamin C undergo a variety of operations such as cooking, processing, freezing, and thawing before consumption. Most of the processing techniques involve thermal and nonthermal methods. These methods have different effects on antioxidant components, and degree of these effects depends on pH, time, temperature, and matrix of food components. Thermal processing techniques like blanching, pasteurization, baking, drying, and roasting can have both detrimental as well as beneficial effects on phytochemical compounds (Nayak et al. 2015), while nonthermal processing techniques such as irradiation, UV treatment, high hydrostatic pressure treatment, and pulsed electric field treatment do not produce any significant destruction to the health-promoting bioactive compounds and thus improve bio-accessibility and bioavailability (Al-juhaimi et al. 2018) (Table 9.6).

Preservation methods significantly reduce the naturally occurring bioactive compounds in foods. Processing of fruits and vegetables lowers health benefit

Table 9.6 Effects of processing methods—thermal and nonthermal techniques on natural antioxidants from various sources

Sample	Technique	Effects on bioactive compounds	References
Thermal techniques			
Fresh broccoli florets	Cooking	It contains 60.5% of total antioxidant activity, and after microwaving and boiling for 5 min it has been reduced to 35 and 34.7%	Zhang and Hamauzu (2004)
Barley seeds	Roasting	Total phenolic content is decreased to 8.5–49.6% when roasted at 280 °C for 20 s	Sharma and Gujral (2011)
Citrus fruit peel	Drying	Total phenolic content significantly reduced than that in fresh peel when dried at 50 °C–60 °C	Chen et al. (2011)
Leafy vegetables	Blanching	50% reduction in antioxidant content, and after boiling for 15 min, it further reduces to 82% antioxidant activity that has been lost in water	Amin et al. (2006)
Peach puree containing periderm tissue	Blanching then followed by pasteurization	Increases the antioxidant activity by 7–11% than peeled samples	Talcott et al. (2000)
Purple carrot	Blanching	Increases 27% of anthocyanin content in comparison with fresh samples	Uyan et al. (2004)
Red cabbage	Blanching	Anthocyanin content reduces to 59%	Volden et al. (2008)
Raspberries and blueberries canning	Cooking	Antioxidant and phenolic content is increased by 50% and 53%, respectively	Sablani et al. (2010)
Fruit powder blended with corn meal (blueberry, cranberry, and raspberry)	Extrusion	Reduces anthocyanin content up to 90% for all dried fruits except raspberries	Camire et al. (2007)
Non-thermal techniques			
Apple juice	Pasteurized by pulsed electric field of 35 kV/cm, bipolar pulses of 4 ms, 1200 pulses per second	Total phenolic content is decreased by 14.5%, whereas pasteurization at 90 °C for 30 s reduced the antioxidant activity up to 32.2%.	Aguilar-Rosas et al. (2007)

(continued)

Table 9.6 (continued)

Sample	Technique	Effects on bioactive compounds	References
Strawberry juice	High-intensity pulsed electric field	80% of anthocyanin is retained	Odriozola-Serrano et al. (2009)
Blackberry juice	Sonication using ultrasound	Reduces anthocyanin content by 5%	Tiwari et al. (2009)
Pomegranate peel powder	γ-Irradiation (10 kGy)	Increased total phenolic content by 4 and 12%, respectively	Mali et al. (2012)
Navel orange fruit	γ-Irradiation (100–700 kGy) followed by storage of 3 weeks at 5 °C	Vitamin C and total phenolics remained unaffected	McDonald et al. (2013)
Pineapple juice	UV treatment	Vitamin C content is higher rather than conventional heating	Goh et al. (2012)
Tomato puree	High hydrostatic pressure	Non-significant decrease in antioxidant content	Patras et al. (2008)
Mixed orange and carrot juice	High hydrostatic pressure followed by storage at a temperature of 4 °C for 21 days	No change takes places in antioxidant, carotene, and ascorbic acid content	Fernández García et al. (2000)

capacity in comparison to fresh ones. Furthermore, in fruits and vegetables the retention of phytochemical depends mostly on the processing and preparation of food before consumption, which is associated with their environmental conditions and sensitivity towards oxidation. Recent studies have shown that food processing techniques have optimistic effects on the quality and health-promoting benefits of food items, e.g., antioxidant activity was higher in case of processed corn and tomato than raw ones as the bound phenolic content is released in the food matrix at maximum level (Dewanto et al. 2002a, 2002b). Carotenes and lycopenes are found to be very heat-resistant and thus cause no change or little to the naturally occurring antioxidants even after prolonged or intense heat treatments like cooking, pasteurization, and sterilization. However, in some cases, loss of natural antioxidants takes pace during food processing as these compounds are relatively heat unstable, e.g., vitamin C and polyphenols in the Maillard reaction (Nicoli et al. 1999).

9.6 Potential Applications of Antioxidants

Antioxidants are the compounds that slow down the autoxidation process or neutralize free radicals of other compounds. They have been used extensively in the following:

- Medical, industrial, and food processing sector in order to delay the oxidation, enhances aroma, flavor, and color.
- Antioxidants have preservative action by preventing the food against deterioration during processing and storage like in oils and fats to prevent spoilage (Atta et al. 2017).
- Some herbs and spices such as sage, oregano, basil, clove, rosemary, thyme, and cinnamon are excellent source of antioxidants. These compounds when supplemented to food-containing unsaturated fatty acids impart antioxidant properties that help to prolong the shelf life and inhibit them from turning rancid under oxidative stress (Hinneberg et al. 2006).
- Synthetic antioxidants such as butylatedhydroxytoluene (BHT), butylated hydroxyanisole (BHA), and propyl gallate (PG, E310) effectively inhibit oxidation and have widely been used in therapeutic, food, and cosmetic industries as antioxidants (Anbudhasan et al. 2014).
- Natural antioxidants like vitamin C and E306-vitamin E, plant extracts (grape seed and tea), and many spices and herbs (oregano, basil, olive, rosemary, sage, cinnamon, and clove) impart antioxidant properties to the meat and meat products and is known to be very effective in lipid oxidation and metmyoglobin formation (Arshiya 2013).
- Synthetic antioxidants are used to maintain the quality of RTD—ready to eat food items (Arshiya 2013).
- Antioxidants are also added in industrial products like lubricants to retard oxidation, stabilizers in fuels and gasoline to prevent polymerization (Arshiya 2013).
- They are widely used to inhibit the oxidative degradation of polymers like plastics, rubbers, and adhesives that results in loss of flexibility and strength.
- Synthetic antioxidants are added to the pharmaceutical products to enhance the shelf life of product by inhibiting the oxidation of unsaturated double bonds of fatty acids and enhance the stability of therapeutic agents (Shebis et al. 2013).
- Antioxidants are served as a precursor for the development of novel drug as several bioactive compounds found in plants are used for it (Pérez and Aguilar 2013).

9.7 Conclusion

Food contains significant number of compounds with potential antioxidant capacity. These substances are consumed by humans either through drinks, foods, or inhalation. In humans, free radicals are produced in their body which causes damage and eventually leads to death. Free radicals are generated through oxidation process like lipid peroxidation or rancidity. Rancidity is caused by using the same oil continuously or by re-using the fried oil which have already been used for long time. Reason behind this could be economic sometimes but leads to deterioration of health badly. Antioxidants act as an inhibitor for reactions caused due to oxidation through several mechanisms. Moreover, synthetic antioxidants become necessary, as some foods are deficient in natural antioxidants and can easily damage the product during processing or storage. There are also several different food additives that have strong antioxidant capacity and protects the food against oxidation thereby prolongs the shelf life. Antioxidants from cereals, fruits, vegetables, and beverages play an essential role for human health, e.g., prevention of chronic diseases such as cancer, tumor, CVD, and reduces the risk of other harmful diseases. The main aim of extraction of antioxidant from plant source is to separate the solute molecules form the by-products of plant for performing the efficient extraction method. The extraction efficiency is based on concentration and type of solvent used, time, temperature, and pH of extraction method. Thus, the further research can be done to use natural extracts for the production of healthier foods and to increase the quality and value-added products.

References

Adil IH, Yener ME, Bayındırlı A (2008) Extraction of total phenolics of sour cherry pomace by high pressure solvent and subcritical fluid and determination of the antioxidant activities of the extracts. Sep Sci Technol 43(5):1091–1110

Aguilar-Rosas SF, Ballinas-Casarrubias ML, Nevarez-Moorillon GV, Martin-Belloso O, Ortega-Rivas E (2007) Thermal and pulsed electric fields pasteurization of apple juice: effects on physicochemical properties and flavour compounds. J Food Eng 83(1):41–46

Al-juhaimi F, Ghafoor K, Ozcan MM, Jahurul MHA, Babiker EE, Jinap S, Sahena F, Sharifudin MS, Zaidul ISM (2018) Effect of various food processing and handling methods on preservation of natural antioxidants in fruits and vegetables. J Food Sci Technol 55(11):4492–4504

Alupului A, Calinescu I, Lavric V (2012) Microwave extraction of active principles from medicinal plants. UPB Sci Bull Ser B 74:129–142

Amin I, Norazaidah Y, Hainida KE (2006) Antioxidant activity and phenolic content of raw and blanched Amaranthus species. Food Chem 94(1):47–52

Anbudhasan P, Surendraraj A, Karkuzhali S, Sathishkumaran P (2014) Natural antioxidants and its benefits. Int J Food Nutr Sci 3(6):225–232

Arshiya S (2013) The antioxidant effect of certain fruits: a review. J Pharm Sci Res 5:265–268

Asofiei I, Calinescu I, Gavrila AI, Ighigeanu D, Martin D, Matei C (2017) Microwave hydrodiffusion and gravity, a green method for the essential oil extraction from ginger—energy considerations. UPB Sci Bull 79(4)

Atta EM, Mohamed NH, Abdelgawad AA (2017) Antioxidants: an overview on the natural and synthetic types. Eur Chem Bull 6(8):365–375

Boulekbache-Makhlouf L, Medouni L, Medouni-Adrar S, Arkoub L, Madani K (2013) Effect of solvents extraction on phenolic content and antioxidant activity of the byproduct of eggplant. Ind Crop Prod 49:668–674

Cadoni E, Giorgi MR, Medda E, Poma G (2000) Supercritical CO_2 extraction of lycopene and β-carotene from ripe tomatoes. Dyes Pigments 44:27–32

Camire ME, Dougherty MP, Briggs JL (2007) Functionality of fruit powders in extruded corn breakfast cereals. Food Chem 101:765–770

Cao G, Russell RM, Lischner N, Prior RL (1998) Serum antioxidant capacity is increased by consumption of strawberries, spinach, red wine or vitamin C in elderly women. J Nutr 128 (12):2383–2390

Chandrasekhar J, Madhusudhan MC, Raqhavarao KSMS (2012) Extraction of anthocyanins from red cabbage and purification using adsorption. Food Bioprod Process 90:615–623

Chang SK, Alasalvar C, Bolling BW, Shahidi F (2016) Nuts and their co-products: the impact of processing (roasting) on phenolics, bioavailability, and health benefits—a comprehensive review. J Funct Foods 26:88–122

Chemat F, Khan MK (2011) Applications of ultrasound in food technology: processing, preservation and extraction. Ultrason Sonochem 18(4):813–835
Chemat F, Abert-Vian M, Visinoni F (2008) Microwave hydrodiffusion for isolation of natural products. Eur Patent 1(955):749
Chen ML, Yang DJ, Liu SC (2011) Effects of drying temperature on the flavonoid, phenolic acid and antioxidative capacities of the methanol extract of citrus fruit (Citrus sinensis (L.) Osbeck) peels. Int J Food Sci Technol 46(6):1179–1185
Cheng X, Bi LW, Zhao ZD, Chen YX (2015) Advances in enzyme assisted extraction of natural products. In: Yarlagadda P (ed) AER—Advances in engineering research, vol 27, 3rd edn. Atlantis Press, Paris, pp 371–375
Chew KK, Khoo MZ, Ng SY, Thoo YY, Wan Aida WM, Ho CW (2011) Effect of ethanol concentration, extraction time and extraction temperature on the recovery of phenolic compounds and antioxidant capacity of Orthosiphon stamineus extracts. Int Food Res J 18 (4):1427
Cravottoa G, Boffaa L, Mantegnaa S, Peregob P, Avogadrob M, Cintasc P (2008) Improved extraction of vegetable oils under highintensity ultrasound and/or microwaves. Ultrason Sonochem 15:898–902
Crespy V, Morand C, Besson C, Manach C, Demigne C, Remesy C (2002) Quercetin, but not its glycosides, is absorbed from the rat stomach. J Agric Food Chem 50(3):618–621
Cvetkovic D, Fiedor L, Fiedor J, Wiśniewska-Becker A, Markovic D (2013) Molecular base for carotenoids antioxidant activity in model and biological systems: the health-related effects. Food Sources, Production and Health Benefits, Carotenoids, pp 93–126
Da Silva RPFF, Rocha-Santos TAP, Duarte AC (2016) Supercritical fluid extraction of bioactive compounds. TrAC-Trends Anal Chem 76:40–51
Dahmoune F, Nayak B, Moussi K, Remini H, Madani K (2015) Optimization of microwave-assisted extraction of polyphenols from Myrtus communis L. leaves. Food Chem 166:585–595
Dewanto V, Wu XZ, Liu RH (2002b) Processed sweet corn has higher antioxidant activity. J Agric Food Chem 50:4959–4964
Dewanto V, Wu XZ, Adom KK, Liu RH (2002a) Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. J Agric Food Chem 50:3010–3014
Dhobi M, Mandal V, Hemalatha S (2009) Optimization of microwave assisted extraction of bioactive flavonolignan-Silybinin. J Chem Metrol 3(1):13–23
Do QD, Angkawijaya AE, Tran-Nguyen PL, Huynh LH, Soetaredjo FE, Ismadji S (2014) Effect of extraction solvent on total phenol content, total flavonoid content, and antioxidant activity of Limnophila aromatic. J Food Drug Anal 22:296–302
Durling NE, Catchpole OJ, Grey J, Webby R, Mitchell K, Foo L, Perry N (2007) Extraction of phenolics and essential oil from dried sage (Salvia officinalis) using ethanol–water mixtures. Food Chem 101(4):1417–1424
El-Darra N, Grimi-Eugene N, Nicolas V, Maroun LR (2013) Extraction of polyphenols from red grape pomace assisted by pulsed ohmic heating. Food Bioproc Tech 6:1281–1289
Espada-Bellido E, Ferreiro-González M, Carrera C, Palma M, Barroso CG, Barbero GF (2017) Optimization of the ultrasound-assisted extraction of anthocyanins and total phenolic compounds in mulberry (Morus nigra) pulp. Food Chem 219:23–32
Fernández García A, Butz P, Tauscher B (2000) Does the antioxidant potential of high pressure treated apple juice change during storage? Int J High Press Res 19(1–6):153–160
Fiedor J, Burda K (2014) Potential role of carotenoids as antioxidants in human health and disease. Nutrients 6(2):466–488
Finley JW, Kong AN, Hintze KJ, Jeffery EH, Ji LL, Lei XG (2011) Antioxidants in foods: state of the science important to the food industry. J Agric Food Chem 59(13):6837–6846
Florez N, Conde E, Dominguez H (2015) Microwave assisted water extraction of plant compounds. J Chem Technol Biotechnol 90:590–607
Ghafoor K, Choi YH, Jeon JY, Jo IH (2009) Optimization of ultrasound-assisted extraction of phenolic compounds, antioxidants, and anthocyanins from grape (*Vitis vinifera*) seeds. J Agric Food Chem 57:4988–4994

Ghafoor K, Park J, Choi YH (2010) Optimization of supercritical carbon dioxide extraction of bioactive compounds from grape peel (Vitis labrusca B.) by using response surface methodology. Innov Food Sci Emerg Technol 11:485–490

Giannuzzo AN, Boggetti HJ, Nazareno MA, Mishima HT (2003) Supercritical fluid extraction of naringin from the peel of citrus paradise. Phytochem Anal 14:221–223

Goh SG, Noranizan M, Leong CM, Sew CC, Sobhi B (2012) Effect of thermal and ultraviolet treatments on the stability of antioxidant compounds in single strength pineapple juice throughout refrigerated storage. Int Food Res J 19:1131–1136

Gomez-Garcia R, Martinez-Avila GCG, Aguilar CN (2012) Enzyme assisted extraction of antioxidative phenolics from grape (*Vitis vinifera* L.) residues. 3 Biotech 2:297–300

González-Montelongo R, Lobo MG, González M (2010) The effect of extraction temperature, time and number of steps on the antioxidant capacity of methanolic banana peel extracts. Sep Purif Technol 71(3):347–355

Hadiyanto H, Sutanto AA, Suharto Y (2014) Ultrasound assisted extraction of antioxidant from Coleus tuberosus peels. Carpathian J Food Sci Technol 6(1):58–65

Halliwell B (1990) How to characterize a biological antioxidant. Free Radic Res Commun 9 (1):1–32

Haminiuk CW, Maciel GM, Plata-Oviedo MS, Peralta RM (2012) Phenolic compounds in fruits—an overview. Int J Food Sci Technol 47(10):2023–2044

Handa SS, Khanuja SPS, Longo G, Rakesh DD (2008) Extraction technologies for medical and aromatic plants. ICS Unido Trieste, Trieste

Hannum SM (2004) Potential impact of strawberries on human health: a review of the science. Crit Rev Food Sci Nutr 44(1):1–17

He L, Zhang H, Xu C, Yuan F, Knez Z, Novak Z et al (2012) Subcritical water extraction of phenolic compounds from pomegranate (Punica granatum L.) seed residues and investigation into their antioxidant activities with HPLC–ABTS.+ assay. Food Bioprod Process 90(2):215–223

He Y, Lu Q, Liviu G (2015) Effects of extraction processes on the antioxidant activity of apple polyphenols. J Food 13(4):603–606

Herrera MC, Luque-de-Castro MD (2004) Ultrasound-assisted extraction for the analysis of phenolic compounds in strawberries. Anal Bioanal Chem 379:1106–1112

Hinneberg I, Dorman DHJ, Hiltunen R (2006) Antioxidant activities of extracts from selected culinary herbs and spices. Food Chem 97:122–129

Ibanez E, Herrero M, Mendiola JA, Castro-Puyana M (2012) Extraction and characterization of bioactive compounds with health benefits from marine resources: macro and micro algae, cyanobacteria, and invertebrates. In: Hayes M (ed) Marine bioactive compounds: sources. Characterizationand Applications. Springer, New York, NY, pp 55–98

Lee JH, Ko MJ, Chung MS (2018) Subcritical water extraction of bioactive components from red ginseng (Panax ginseng C.A. Meyer). J Supercrit Fluids 133:177–183

Karakama, K. (2011). Methods for the characterization of deposition and transport of magnetite particles in supercritical water. (doctoral dissertation) Vancouver: University of British Columbia

Khan MK, Abert-Vian M, Fabiano-Tixier A-S, Dangles O, Chemat F (2010) Ultrasound-assisted extraction of polyphenols (flavanone glycosides) from orange (Citrus sinensis L.) peel. Food Chem 119(2):851–858

Khorassani MA, Taylor LT (2004) Sequential fractionation of grape seeds into oils, polyphenols, and procyanidins via a single system employing CO_2-based fluids. J Agric Food Chem 52:2440–2444

Leong SY, Oey I (2012) Effects of processing on anthocyanins, carotenoids and vitamin C in summer fruits and vegetables. Food Chem 133(4):1577–1587

Li BB, Smith B, Hossain MM (2006) Separation and purification in the food industry extraction of phenolics from citrus peels: II. Enzyme assisted extraction method. Sep Purif Technol 48:189–196

Li Y, Fabiano-Tixier AS, Tomao V, Cravotto G, Chemat F (2013) Green ultrasound-assisted extraction of carotenoids based on the bio-refinery concept using sunflower oil as an alternative solvent. Ultrason Sonochem 20:12–18

Liazid A, Guerrero RF, Cantos E, Palma M, Barroso CG (2011) Microwave assisted extraction of anthocyanins from grape skins. Food Chem 124:1238–1243

Liu JJ, Gasmalla MAA, Li P, Yang R (2016) Enzyme-assisted extraction processing from oilseeds: principle, processing and application. Innov Food Sci Emerg Technol 35:184–193

Liu RH (2004) Potential synergy of phytochemicals in cancer prevention: mechanism of action. J Nutr 134:3479s–3485s

Liu RH (2007) Whole grain phytochemicals and health. J Cereal Sci 46(3):207–219

Luengo E, Condón-Abanto S, Condón S, Álvarez I, Raso J (2014) Improving the extraction of carotenoids from tomato waste by application of ultrasound under pressure. Sep Purif Technol 136:130–136

Maier T, Goppert A, Kammerer DR, Schieber A, Carle R (2008) Optimization of a process for enzyme-assisted pigment extraction from grape (*Vitis vinifera* L.) pomace. Eur Food Res Technol 227:267–275

Mali A, Khedkar K, Lele S (2012) Effect of gamma irradiation on total phenolic content and in vitro antioxidant activity of pomegranate (Punica granatum L.) peels. Food Nutr Sci 2:428–433

Maran JP, Priya B, Manikandan S (2014) Modeling and optimization of supercritical fluid extraction of anthocyanin and phenolic compounds from Syzygium cumini fruit pulp. J Food Sci Technol 51:1938–1946

Mattila P, Hellström J, Törrönen R (2006) Phenolic acids in berries, fruits, and beverages. J Agric Food Chem 54(19):7193–7199

McDonald H, Arpaia ML, Caporaso F, Obenland D, Were L, Rakovski C, Prakash A (2013) Effect of gamma irradiation treatment at phytosanitary dose levels on the quality of 'lane late' navel oranges. Postharvest Biol Technol 86:91–99

Michel T, Destandau E, Elfakir C (2011) Evaluation of a simple and promising method for extraction of antioxidants from sea buckthorn (Hippophaë rhamnoides L.) berries: pressurised solvent-free microwave assisted extraction. Food Chem 126(3):1380–1386

Murga R, Ruiz R, Beltran S, Cabezas JL (2000) Extraction of natural complex phenols and tannins from grape seeds by using supercritical mixtures of carbon dioxide and alcohol. J Agric Food Chem 48:3408–3412

Mushtaq M, Sultana B, Bhatti HN, Asghar M (2015) RSM based optimized enzyme-assisted extraction of antioxidant phenolics from underutilized watermelon (Citrullus lanatus Thunb.) rind. J Food Sci Technol 52:5048–5056

Nayak B, Liu RH, Tang J (2015) Effect of processing on phenolic antioxidants of fruits, vegetables, and grains—a review. Crit Rev Food Sci Nutr 55:887–918

Nguyen TH, Smagghe G, Gonzales GB, van Camp J, Raes K (2014) Enzyme-assisted extraction enhancing the phenolic release from cauliflower (Brassica oleracea L. Var. Botrytis) outer leaves. J Agric Food Chem 62:7468–7476

Nicoli MC, Anese M, Parpinel MT, Franceschi S, Lerici CR (1997) Loss and/or formation of antioxidants during food processing and storage. Cancer Lett 114(1–2):71–74

Nicoli MC, Anese M, Parpinel M (1999) Influence of processing on the antioxidant properties of fruit and vegetables. Trends Food Sci Technol 10:94–100

Odriozola-Serrano I, Soliva-Fortuny R, Martin-Belloso O (2009) Impact of high-intensity pulsed electric fields variables on vitamin C, anthocyanins and antioxidant capacity of strawberry juice. LWT–Food Sci Technol 42:93–100

Oliveira DA, Salvador AA, Smania A, Smania EFA, Maraschin M, Ferreira SRS (2013) Antimicrobial activity and composition profile of grape (*Vitis vinifera*) pomace extracts obtained by supercritical fluids. J Biotechnol 164:423–432

Oroian M, Escriche I (2015) Antioxidants: characterization, natural sources, extraction and analysis. Food Res Int 74(2015):10–36

Padayatty SJ, Katz A, Wang Y, Eck P, Kwon O, Lee JH, Levine M (2003) Vitamin C as an antioxidant: evaluation of its role in disease prevention. J Am Coll Nutr 22(1):18–35
Pasrija D, Anandharamakrishnan C (2015) Techniques for extraction of green tea polyphenols: a review. Food Bioproc Tech 8:935–950
Patras A, Brunton N, Da Pieve S, Butler F, Downey G (2008) Effect of high pressure processing on antioxidant activity and instrumental colour of tomato and carrot purees. Innov Food Sci Emerg Technol 10:16–22
Pereira P, Cebola MJ, Oliveira MC, Bernardo-Gil MG (2016) Supercritical fluid extraction vs. conventional extraction of myrtle leaves and berries: comparison of antioxidant activity and identification of bioactive compounds. J Supercrit Fluids 113:1–9
Pérez JAM, Aguilar TAF (2013) Chemistry of natural antioxidants and studies performed with different plants collected in Mexico. In: Morales-González JA (ed) Oxidative stress and chronic degenerative diseases —a role for antioxidants. London, Intec, pp 59–81
Perino-Issartier S, Huma Z-E, Abert-Vian M, Chemat F (2011) Solvent free microwave-assisted extraction of antioxidants from sea buckthorn (Hippophae rhamnoides) food by-products. Food Bioprocess Technol 4:1020–1028
Sablani SS, Andrews PK, Davies NM, Walters T, Saez H, Syamaladevi RM, Mohekar PR (2010) Effect of thermal treatments on phytochemicals in conventionally and organically grown berries. J Sci Food Agric 90:769–778
Samaranayaka AG, Li-Chan EC (2011) Food-derived peptidic antioxidants: a review of their production, assessment, and potential applications. J Funct Foods 3(4):229–254
Sandur SK, Ichikawa H, Pandey MK, Kunnumakkara AB, Sung B, Sethi G, Aggarwal BB (2007) Role of pro-oxidants and antioxidants in the anti-inflammatory and apoptotic effects of curcumin (diferuloylmethane). Free Radic Biol Med 43(4):568–580
Saravana PS, Tilahun A, Gerenew C (2018) Subcritical water extraction of fucoidan from Saccharina japonica: optimization, characterization and biological studies. J Appl Phycol 30 (1):579–590
Selvamuthukumaran M, Shi J (2017) Recent advances in extraction of antioxidants from plant by-products processing industries. Food Qual Safety 1:61–81
Serra AT, Seabra IJ, Braga MEM, Bronze MR, de Sousa HC, Duarte CMM (2010) Processing cherries (Prunus avium) using supercritical fluid technology. Part 1: recovery of extract fractions rich in bioactive compounds. J Supercrit Fluids 55:184–191
Shahidi F, Ho C (2005) Phenolics in food and natural health products: an overview. ACS Symp Ser 909:1–8
Shahidi F, Ambigaipalan P (2015) Phenolics and polyphenolics in foods, beverages and spices: antioxidant activity and health effects—a review. J Funct Foods 18:820–897
Sharma P, Gujral HS (2011) Effect of sand roasting and microwave cooking on antioxidant activity of barley. Food Res Int 44:235–240
Shebis Y, Iluz D, Kinel-Tahan Y, Dubinsky Z, Yehoshua Y (2013) Natural antioxidants: Function and sources. Food Nutr Sci 4:643–649
Smeriglio A, Barreca D, Bellocco E, Trombetta D (2016) Chemistry, pharmacology and health benefits of anthocyanins. Phytother Res 30(8):1265–1286
Song W, Derito CM, Liu MK, He X, Dong M, Liu RH (2010) Cellular antioxidant activity of common vegetables. J Agric Food Chem 58:6621–6629
Strati IF, Oreopoulou V (2011) Effect of extraction parameters on the carotenoid recovery from tomato waste. Int J Food Sci Technol 46(1):23–29
Suarez M, Romero MP, Ramo T, Macia A, Motilva MJ (2009) Methods for preparing phenolic extracts from olive cake for potential application as food antioxidants. J Agric Food Chem 57 (4):1463–1472
Talcott ST, Howard LR, Brenes CH (2000) Contribution of periderm material and blanching time to the quality of pasteurized peach puree. J Agric Food Chem 48:4590–4596
Tiwari BK, O'Donnell CP, Cullen PJ (2009) Effect of sonication on retention of anthocyanins in blackberry juice. J Sci Food Agric 93:166–171

Tsakona S, Galanakis CM, Gekas V (2012) Hydro-ethanolic mixtures for the recovery of phenols from Mediterranean plant materials. Food Bioproc Tech 4:1384–1393
Tsubaki S, Sakamoto M, Azuma J (2010) Microwave-assisted extraction of phenolic compounds from tea residues under autohydrolytic conditions. Food Chem 123(4):1255–1258
Tsubaki S, Sakamoto M, Azuma J (2000) Microwave-assisted extraction of phenolic compounds from tea residues under autohydrolytic conditions. Food Chem 123:1255–1258
Uyan SE, Baysal T, Yurdagel O, El SN (2004) Effects of drying process on antioxidant activity of purple carrots. Nahrung/Food 48:57–60
Van Tang N, Hong NTP, Bowyer MC, van Altena IA, Scarlett CJ (2016) Influence of solvents and novel extraction methods on bioactive compounds and antioxidant capacity of Phyllanthus amarus. Chem Pap 70:556–566
Vasta V, Priolo A (2006) Ruminant fat volatiles as affected by diet: A review. Meat Sci 73 (2):218–228
Veggi PC, Cavalcanti RN, Meireles MAA (2011) Modifier effects on supercritical fluid extraction (SFE) of some Brazilian plants: antioxidant activity and economical evaluation. Proc Food Sci:1717–1724
Visentin A, Rodriguez-Rojo S, Navarrette A, Maestri D, Cocero MJ (2012) Precipitation and encapsulation of rosemary antioxidants by supercritical anti-solvent process. J Food Eng 109 (1):9–15
Volden J, Borge GIA, Bengtsson GB, Hansen M, Thygesen IE, Wicklund T (2008) Effect of thermal treatment on glucosinolates and antioxidant-related parameters in red cabbage (Brassica oleracea L. ssp capitata f. rubra). Food Chem 109:595–605
Wang H, Helliwell K (2001) Determination of flavonols in green and black tea leaves and green tea infusion by high-performance liquid chromatography. Food Res Int 34(2–3):223–227
Williams OJ, Raghavan GSV, Orsat V, Dai J (2004) Microwave-assisted extraction of capsaicinoids from capsicum fruit. J Food Biochem 28:113–122
Xu D-P, Li Y, Meng X, Zhou T, Zhou Y, Zheng J, Zhang J-J, Li H-B (2017) Natural antioxidants in foods and medicinal plants: extraction, assessment and resources. Int J Mol Sci 18:96
Zaghdoudi K, Framboisier X, Frochot C, Vanderesse R, Barth D, Kalthoum-Cherif J, Blanchard F, Guiavarc'h Y (2016) Response surface methodology applied to supercritical fluid extraction (SFE) of carotenoids from persimmon (Diospyros kaki L.). Food Chem 208:209–219
Zhang D, Hamauzu Y (2004) Phenolics, ascorbic acid, carotenoids and antioxidant activity of broccoli and their changes during conventional and microwave cooking. Food Chem 88:503–509
Zheng X, Wang X, Lan Y, Shi J, Xue SJ, Liu C (2009) Application of response surface methodology to optimize microwave-assisted extraction of silymarin from milk thistle seeds. Sep Purif Technol 70:34–40
Zhou K, Raffoul JJ (2012) Potential anticancer properties of grape antioxidants. J Oncol 2012
Zill-e-Huma MAV, Maingonnat JF, Chemat F (2009) Clean recovery of antioxidant flavonoids from onions: optimising solvent free microwave extraction method. J Chromatogr A 1216:7700–7707
Zougagh, M., Valcarcel, M. and Rios, A. (2004). Supercritical fluid extraction: a critical review of its analytical usefulness. Trends Anal Chem, 23: 399–405

Dietary Fiber as a Functional Food

10

Kausar Jahan, Ovais Shafiq Qadri, and Kaiser Younis

Abstract

Not all the nutrients in the food are digestible to humans. The indigestible part of the food is known as dietary fiber. They are usually polysaccharides and can be soluble or insoluble in water. Soluble fibers are found in oat bran, barley, nuts, seeds, beans, lentils, peas, and some fruits and vegetables and mainly include pectin, beta-Glucans, and inulin. Insoluble fiber is found in foods such as wheat bran, vegetables, and whole grains and mainly includes cellulose, hemicellulose, and psyllium. Dietary fiber performs various roles in the digestive tract. It provides good satiety value thus decrease the energy intake. It increases bowel movement and prevents constipation. It serves as food to the gut microflora, which ferments it, and produces short-chain fatty acids. These short-chain fatty acids are useful for gut health, which also helps to reduce body cholesterol. Dietary fiber consumption also absorbs the glucose in the digestive tract, hence retards its rate of release to the blood stream. This helps in maintaining the body blood glucose level. This may help diabetic people from an abrupt increase in body glucose level. Nowadays consumption of dietary fiber is encouraged and is added to various food recipes as a functional ingredient.

Keywords

Dietary fiber · Soluble dietary fiber · Insoluble dietary fiber · Functional food · Diabetes · Cholesterol · Constipation

K. Jahan · K. Younis (✉)
Department of Bioengineering, Integral University, Lucknow, Uttar Pradesh, India

O. S. Qadri
Department of Biotechnology, Thapar Institute of Engineering and Technology, Patiala, Punjab, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_10

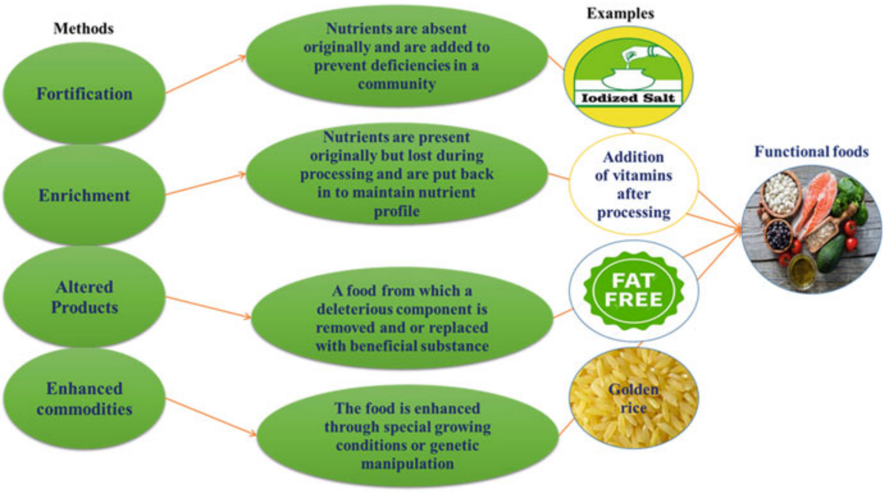


Fig. 10.1 Methods of functional food formation

10.1 Introduction

10.1.1 Functional Food

Functional foods are defined as "Foods that may provide health benefits beyond basic nutrition" and "Food similar in appearance to conventional food that is intended to be consumed as part of a normal diet, but has been modified to subserve physiological roles beyond the provision of simple nutrient requirements" (Bech-Larsen and Grunert 2003). It should be similar to normal food with respect to structure, size, and amount of intake. Therefore, it should not be consumed or considered as a medicine (Diplock et al. 1999). In the starting phase, fortification of functional foods with vitamins and/or minerals was performed; however, these foods are also added with bioactive micronutrients, for example, omega-3 fatty acids, dietary fiber, and phytosterols. Nowadays, food industries are developing functional foods with multiple health benefits (Sloan 2000, 2002, 2004). The health benefits of functional foods are due to the presence of bioactive compounds and these include vitamins, minerals, antioxidants, polyphenols, peptides, and dietary fiber. These bioactive compounds are added to the functional foods through various ways like fortification, enrichment, altering the product, and enhancing the commodities as shown in Fig. 10.1.

10.1.2 Dietary Fiber

Dietary fiber is the part of food which our body cannot digest and its benefits have been claimed since Hippocrates time 430 BC. He had mentioned laxative properties of rough wheat flour over the refined flour. The definition of dietary fiber has changed from time to time and landed on the most acceptable form which states that "Any dietary component that reaches the colon without being absorbed in a healthy human gut" (Ha et al. 2000). This definition has increased the limits beyond indigestible cell wall materials as previously defined by Trowell (1972). Dietary fiber is commonly known as roughage which helps to increase the bulk volume of fecal matter which in turn prevents constipation (Mudgil and Barak 2019). Dietary fibers can be classified on the basis of solubility, fermentability, composition, site of digestion, products of digestion, and physiological effects. However, the most common classification is on the basis of solubility. Soluble dietary fibers are soluble in water, while non-soluble fibers are insoluble in water (Tungland and Meyer 2002). Soluble dietary fibers include inulin, pectin, beta-glucan, galactomammans, polydextrose, psyllium, fructooligosaccharides, and dextrins. Insoluble dietary fibers include celluloses, hemicelluloses, lignins, resistant starches, arabinoxylans, and nonstarch polysaccharides. In addition of health benefits (Table 10.1), dietary fibers are added to food products to alter their properties like viscosity, water-holding capacity, and oil-holding capacity which in turn helps to enhance the product quality in terms of nutrition, cooking yield, texture, shape, and size (Younis and Ahmad 2015, 2018, 2017; Younis et al. 2015a, b).

10.2 Mechanism

Dietary fiber is regarded as a functional food as it has been claimed to prevent the various diseases like cardiovascular disease, diabetes, gastrointestinal disorders, immune system, and constipation (Anderson et al. 2009). Sufficient information is available in support of functional benefits of dietary fiber. Some of the important chronic diseases and their relationship with dietary fiber are described as under:

Cardiovascular disease: It is the narrowing of the blood vessels caused by the building of fatty plaques resulting in coronary heart disease, stroke, and hypertension. These are attributed to the sedentary lifestyle, bad food habits, and cigarette smoking (Stampfer et al. 2000). The deposition of fat in the blood vessels is mainly cholesterol. Cholesterol is of two types, low-density lipoproteins and high-density lipoproteins. Low-density lipoprotein also know as bad cholesterol and is mainly responsible for the fat deposition in the vessels which narrows the diameter and hindrances the blood supply to flow (Gordon et al. 1977). Thus, causing conditions like coronary heart disease, stroke, and hypertension. Soluble fibers have been proven to have hypocholesterolemic effect. Beta-glucan, psyllium, pectin, and guar gum have been identified as viscous soluble fibers which reduced the risk of cardiovascular disease by lowering the serum low-density lipoprotein (Theuwissen

Table 10.1 Dietary fibers and their health benefits

Dietary fiber	Sources	Benefits	References
Insoluble dietary fiber	Wheat bran	Reduces risk of breast and colon cancers, cardiovascular diseases, obesity, and gastrointestinal diseases	Stevenson et al. (2012)
Soluble dietary fiber (β-glucans)	Oats, barley	Reduces risk of cardiovascular disease; protects against heart disease and some cancers; lower LDL and total cholesterol	Pinns and Kaur (2006); Pomeroy et al. (2001)
Soluble fiber	Psyllium	Reduces risk of cardiovascular disease; protects against heart disease and some cancers; lower LDL and total cholesterol	Warnberg et al. (2009)
Fructooligosaccharides (FOS)	Jerusalem artichokes, shallots, onion powder, asparagus, sugar beet, garlic, chicory, onion, wheat, honey, banana, barley, tomato and rye	Stimulate the growth of nonpathogenic (bifidobacteria) intestinal microflora and decreases the growth of potentially pathogenic bugs and enhances the immune system	Sridevi et al. (2014)
Isomaltulose	Honey, sugarcane juice	Prevention of cardio-metabolic diseases and cancers	Shyam et al. (2018)
Xylooligosaccharides	Bamboo shoots, fruits, vegetables, milk, honey, and wheat bran	Prevent gastrointestinal infection and reduce duration in diarrhea; maintain and improve a balanced intestinal microflora	Vázquez et al. (2000), Kumar et al. (2012)
Galactooligosaccharides	Human's milk and cow's milk	Stimulate the growth of beneficial bacteria, which inhibit the growth of pathogenic bacteria, enhance immune response, improve stool frequency, and relieve symptoms of constipation	Ibrahim (2009)

(continued)

Table 10.1 (continued)

Dietary fiber	Sources	Benefits	References
Cyclodextrins	Water-soluble glucans	Regulate and control blood glucose for diabetes, reduce lipid level for patients with hyperlipidemia symptoms, control body weight, and for healthy colon	Ibrahim (2009)
Raffinose oligosaccharides	Seeds of legumes, lentils, peas, beans, chickpeas, mallow composite, and mustard	Increase bifidobacteria and relieve diarrhea	Qiang et al. (2009)
Soybean oligosaccharide	Soybean	Exclusion of potential pathogens	Qiang et al. (2009)
Lactulose	Lactose (Milk)	Bifidogenic agent and functional prebiotic additive	Nooshkam et al. (2018)
Enzyme-resistant dextrin	Potato starch	Bifidogenic effect and stimulate the growth of gut microbiota, thus limiting the growth of *Clostridium* strains	Barczynska et al. (2015)
Arabinoxylooligosaccharides	Wheat bran	Prebiotic potential (production of short-chain fatty acid and lactic acid, bifidogenic activity)	Gullon et al. (2014)

and Mensink 2008). One of the possible mechanisms of cardiovascular disease prevention by dietary fiber has been summarized in Fig. 10.2.

Diabetes: Glucose is the main energy source for the cells. After digestion of polysaccharides in the digestive tract, the monosaccharide is absorbed through the small intestines into the blood. Glucose is carried by a hormone called insulin to get into the cells for energy. However, in diabetic condition the blood glucose does not get into the cells due to which the sugar in blood remains high (Gropper et al. 2017). High blood sugar level causes damage to blood vessels and leads to heart disease and stroke, neuropathy which causes the nerve damage, eye damage which causes low vision and blindness, gum disease and dental problems, sexual and bladder problems and foot problems such as callus which leads to pain and infection (Skyler 2012). Food has been categorized on the bases of glycemic index and is grouped as low ($\leq$55), medium (56–69), and high ($\geq$70) glycemic index foods (Jenkins et al. 1981). High glycemic indexed foods increase blood glucose abruptly and include the high starch-containing foods like white bread. Consumption of dietary fiber on regular basis has been found to have significant effect on the prevention of diabetes and is

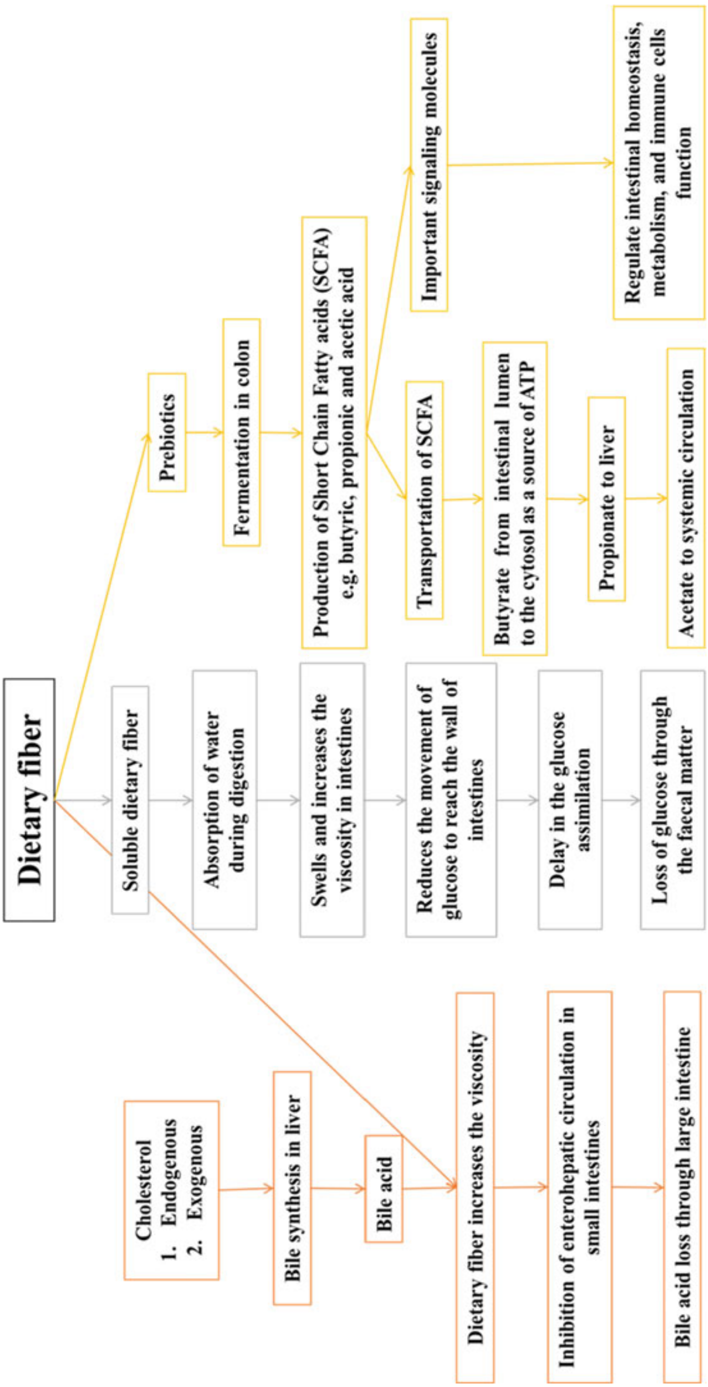


Fig. 10.2 Mechanism of preventing various diseases with dietary fiber

one of the best approaches to control it (Qadri et al. 2017). The well-known mechanism is mentioned in Fig. 10.2.

Gastrointestinal disorders: It includes various diseases and those having a link with the dietary fiber are gastroesophageal reflux disease, peptic ulcer disease, gallbladder disease, appendicitis, diverticular disease, constipation, colorectal cancer, and hemorrhoids. From the past researches, the high intake of the dietary fiber lowered the prevalence of these diseases (Aldoori et al. 1997; Aldoori 1997; Cummings 2001; Tsai et al. 2004; El-Serag et al. 2005; Wu et al. 2007). It is believed that the insoluble dietary fibers soften the stools and reduce the transit time of fecal matter thus reducing the contact time of toxic substances with the intestinal wall. While as the soluble fiber absorbs water and forms a gel which gives the feeling of fullness and most of them act as prebiotics, a food for the probiotics (Anderson et al. 2009).

Immune system: It is the defense mechanism of our body through which our body attacks the foreign invaders to prevent us from the disease. The primary organs of the immune system include thymus and bone marrow, while the secondary organs are the spleen, tonsils, lymph vessels, lymph nodes, adenoids, liver, and skin. About 60% of all lymphocytes in the body are associated with gut lymphoid tissue. Thus makes the gut the largest immune organ of our body (Anderson et al. 2009). The optimum function of gut immunity depends on the gut health which in turn depends on the dietary components of our diet (Vos et al. 2007). Dietary fibers especially prebiotics support the growth of useful bacteria known as probiotics in the gut which maintain the gut health. Inulin, oligofructose, β-glucan, gum arabic, and others have been extensively studied for their favorable effect on the gut health (Younis et al. 2015). The proposed mechanism of enhancing the immune system of gut with the consumption of dietary fiber is shown in Fig. 10.2 (Watzl et al. 2005; Roberfroid 2007; Vieira and Vinolo 2019).

Obesity: It is defined as deposition of excessive fat in the body that leads to impaired health conditions (Ruhee and Suzuki 2018). Obesity can lead to various problems like cardiac diseases, high blood pressure, diabetes, cancers, and depression. Sendentry lifestyle and excessive intake of high-calorie foods are main cause behind this condition. Exercise and less calorie intake are the two ways to prevent the onset of obesity. There is a positive correlation between the consumption of deitry fiber and weight loss supported by various researches (Requena et al. 2016). Consumption of dietary fibers along meals and other foods reduces the calorie intake and provides the feeling of fullness because of their viscous nature, occupying greater volume and delaying the absorption of fat consumed with it, thereby enhancing the satiety value of the fat, which prevents the individuals from the food cramping. Thus reduces the total energy intake (Astrup et al. 1990; Heini et al. 1998; Pasman et al. 1997; Warrilow et al. 2018).

10.3 Scope of Fiber in Functional Food Development

Dietary fiber is naturally present in all the plant foods located in the cell and cell wall. Consumption of fiber-rich foods in the form of salad with daily meals is recommended by nutrition experts. The Recommended Daily Intakes of dietary fiber is 25 g and 21 g for women having age less than 50 and above, respectively. And for the men, the recommended daily intake is 38 g and 30 g having age less than 50 and above, respectively (Maphosa and Jideani 2015). As the fiber is rich in the nonedible portion of foods like bran, fruit peel, and vegetable trimmings which are generally thrown as waste. Being a valuable product, the fiber is extracted from waste by using dry processing, wet processing, chemical, gravimetric, enzymatic, physical, microbial, or a combination of these methods (Bogracheva et al. 2001; Ramirez et al. 2009; Salehifar and Fadaei 2011; Daou and Zhang 2012) depending on the type of fiber. Nowadays, these fibers are used as an ingredient in the food formulation for technological and health benefits. Their physical properties like water-holding capacity, oil-holding capacity, gel-forming ability, swelling capacity, and the rheological properties have made it easy for the manufacturers to design fiber-rich foods with minimum changes in the sensory and the texture. The important fiber-incorporated products available in the market are bakery, dairy, and meat products. In meat products, it is used to replace the animal fat as well as to increase its fiber content. In bakery foods like bread and cake, it is used as humectants to retain the moisture content. In jam and jelly, it is used to form a network to entrap the water. In frozen desserts, it is used as a stabilizer and cryoprotectant to prevent the ice crystal growth. In dairy products, it is used to prevent the whey separation in curd. In dressings, sauces, and spreads, it is used as a thickener, suspending aid, protective colloid, improved mouthfeel, body, and texture. It is used to stabilize the foams, dispersions, suspensions, and emulsions (James and Whistler 1996). The above discussion clearly suggests the possibility of incorporation of dietary fiber in various foods with better quality. However, there is missing research related to the changes due to various unit operations of food processing in physiological behaviors of fibers.

10.3.1 Changes in Dietary Fiber

The physical and chemical properties of fiber can be changed by physical, chemical, and enzymatic changes (Guillon and Champ 2000). During the development of functional foods, various unit operation like grinding, soaking, cooking, extrusion, cooling, packing, and storing is done. The kinetics of water uptake increases after the grinding of the dietary fiber due to increased surface area (Poutanen et al. 1998). Heating changes the ratio of soluble to insoluble fiber, and the combination of heat and mechanical energy leads the overall structural changes which cause changes in the functional properties (Spiller 1986; Roehrig 1988). The formation of protein–fiber complex increases the fiber content of wheat bran when treated through the boiling, cooking, or roasting (Caprez et al. 1986). The quantity of fiber decreases after soaking and cooking of lentils due to the solubilization and decrease in the hemicelluloses (Vidal-Valverde and Frias 1991; Vidal-Valverde et al. 1992; Tatjana et al. 2002). The soluble dietary fiber of potatoes increases and the total fiber decreases with the application of heat; however, there is no change in dietary fiber due to extrusion (Varo et al. 1983). However, research carried out by Camire et al. (1997) on the potato peels revealed that the total dietary fiber increased by the extrusion. Microwave cooking increased the insoluble dietary fiber and resistant starch in potatoes. It is because of the amylopectin enzymes and the formation of the resistant starches (Thed and Philips 1995). Soaking of Bengal gram, cowpea, dry pea, field bean, and green gram showed increased dietary fiber after soaking in water for 12 h (Chopra et al. 2009). From the above findings, the different sources and different unit operations have different effects on the dietary fiber content.

10.4 Undesirable Effects of Dietary Fiber

Despite various benefits, dietary fiber has its negative side. Dietary fiber interacts with other food nutrients in the digestive system and provides hindrances in the absorption. Some of the important interactions are described below:

Mineral: Increased intake of dietary fibers reduces the mineral absorption in the small intestines. Wheat and oat bran addition in diets showed the decreased absorption rates of calcium, magnesium, copper, and zinc (Moak et al. 1987). From the animal studies, the increased dietary fiber content reduced the absorption of the minerals (Donangelo and Eggum 1986). Various in vitro studies also support the impaired absorption of minerals due to their binding with fibers (Claye et al. 1996; Idouraine et al. 1995). There are three reasons for the reduction of the absorption rate of minerals. First, the reduction of transit time does not allow the minerals to get absorbed. Second, dietary fiber directly impairs mineral transportation in the intestines. Third, dietary fiber forms mineral–fiber complex which cannot be broken down and absorbed (Wong and Cheung 2005a, 2005b).

Other: Sudden diet shift from low-fiber to high-fiber diets especially containing guar gum and wheat bran causes the temporary uncomfortable symptoms in the digestive tract like bloating, flatulence, nausea, vomiting, and eructation (Dutta and Hlasko 1985; LSRO 1987). Some studies have found the decrease in bioavailability of fat-soluble vitamins with the fiber consumption. Reinhold (1976) found that the consumption of wheat bran has deleterious effect on the bioavailability of the vitamin D. Riedl et al. (1999) has found that the dietary fiber may partly reduce the bioavailability of the beta carotenoids. Protein bioavailabilty is affected by the antinutrient; however, Chacko and Cummings (1988) has found that the high-fiber diets resulted in nitrogen loss as compared to low-fiber foods.

10.4.1 Regulations of Fiber

A food can be labeled as "source of fiber" or claim having the same meaning, may only be made when it contains at least 3 g of fiber per 100 g or atleast 1.5 g of fiber per 100 kcal. Similarly a food can be labeled as "high fiber" or claim having the same meaning, may only be made when it contains atleast 6 g of fiber per 100 g or atleast 3 g per 100 kcal (EC 2006; FSSAI 2017).

10.5 Conclusion

Dietary fiber has numerous health benefits which categorize it under the functional foods. It has proven to lower the low-density lipoproteins, prevent the abrupt blood glucose level, prevent constipation, reduce the risk of obesity, and improve the gut health. High-fiber foods are recommended to consume on daily basis in the form of salad and fruits. It is very fortunate that the designing of high-fiber foods is also possible because of the physicochemical properties like water-holding capacity, oil-holding capacity, emulsion stability, and swelling ability of the dietary fiber. The incorporation of dietary fiber in foods not only increases the fiber content but also improves the textural and sensory properties of foods. Dietary fiber has been found to impair the nutrition absorption from the intestines; however, it is only true when consumed at higher levels.

Acknowledgment Authors are thankful to the Integral University Lucknow for its kind support.

References

Aldoori WH (1997) The protective role of dietary fiber in diverticular disease. Adv Exp Med Biol 427:291–308

Aldoori WH, Giovannucci EL, Stampfer MJ, Rimm EB, Wing AL, Willett WC (1997) Prospective study of diet and the risk of duodenal ulcer in men. Am J Epidemiol 145:42–50

Anderson JW, Baird P, Davis RH, Ferreri JS, Knudtson M, Koraym A, Waters V, Williams CL (2009) Health benefits of dietary fiber. Nutr Rev 67(4):188–205

Astrup A, Vrist E, Quaade F (1990) Dietry fibre added to very low calorie diet reduces hunger and alleviates constipation. Int J Obes 14:105–112

Barczynska R, Bandurska K, Slizewska K, Litwin M, Szalecki M, Libudzisz Z, Kapusniak J (2015) Intestinal microbiota, obesity and prebiotics. Pol J Microbiol 64(2):93–100

Bech-Larsen T, Grunert KG (2003) The perceived healthiness of functional foods—a conjoint study of Danish, Finnish and American consumers' perception of functional foods. Appetite 40:9–14

Bogracheva T, Cserhalmi Z, Czukor B, Fornal J, Schuster-Gajzago I, Kovacs ET, Lewandowicz G, Soral-Smietana M (2001) Carbohydrates in grain legume seeds: improving nutritional quality and agronomics characteristics. CABI, New York, pp 89–92

Camire ME, Violette D, Dougherty MP, McLaughlin MA (1997) Potato peels dietary fibre composition: effects of peeling and extrusion cooking processes. J Agric Food Chem 45:1404–1409

Caprez A, Arrigoni E, Amado R, Neucom H (1986) Influence of different types of thermal treatment on the chemical composition and physical properties of wheat bran. J Cereal Sci 4:233–239

Chacko A, Cummings JH (1988) Nitrogen losses from the human small bowel: obligatory losses and the effect of physical form of food. Gut 29:809–815
Chopra H, Udipi SA, Ghugre P (2009) Dietary fibre content of selected legumes: varietal differences and effect of processing. J Food Sci Technol 46(3):266–268
Claye SS, Idouraine A, Weber CW (1996) In vitro binding capacity of five fiber sources and their insoluble components for copper and zinc. Plant Foods Hum Nutr 49:257–269
Cummings JH (2001) The effect of dietary fiber on fecalweight and composition. In: Spiller G (ed) Dietary fiber in human nutrition. CRC, Boca Raton, FL, pp 183–252
Daou C, Zhang H (2012) Study on functional properties of physically modified dietary fibres derived from defatted Rice bran. J Agric Sci 4:85–97
Diplock AT, Aggett PJ, Ashwell M, Bornet F, Fern EB, Roberfroid MB (1999) Scientific concepts of functional foods in Europe: Concensus document. Br J Nutr 81(Suppl. 1):S1–S27
Donangelo CM, Eggum BO (1986) Comparative effects of wheat bran and barley husk on nutrient utilization in rats. 2. Zinc, calcium and phosphorus. Br J Nutr 56:269–280
Dutta SK, Hlasko J (1985) Dietary fiber in pancreatic disease: effect of high fiber diet on fat malabsorption in pancreatic insufficiency and in vitro study of the interaction of dietary fiber with pancreatic enzymes. Am J Clin Nutr 41:517–525
EC (2006) Regulation (EC) No 1924/2006 of European Parliament and of the council on nutrition and health claims made on foods. Off J Eur Union. L 404/9–24
El-Serag HB, Satia JA, Rabeneck L (2005) Dietary intake and the risk of gastro-oesophageal reflux disease: a cross sectional study in volunteers. Gut 54:11–17
Food Safety and Standards Authority of India (Claims and advertisement) 2017 F.No. 1–94 (p. 5)
Gordon T, Castelli WP, Hjortland MC, Kannel WB, Dawber TR (1977) High density lipoprotein as a protective factor against coronary heart disease. Am J Med 62(5):707–714. https://doi.org/10.1016/0002-9343(77)90874-9
Gropper SS, Smith JL, Carr TP (2017) Chapter 2: The digestive system: mechanism for nourishing the body and Chapter 3: Carbohydrates. In: Advanced nutrition and human metabolism, 7th edn. Cengage Learning, Belmont, pp 61–106
Guillon F, Champ M (2000) Structural and physical properties of dietary fibres, and consequences of processing on human physiology. Food Res Int 33:233–245
Gullon B, Gullon P, Tavaria F, Pintado M, Gomes AM, Alonso JL, Parajo JC (2014) Structural features and assessment of prebiotic activity of refined arabinoxylooligosaccharides from wheat bran. J Funct Foods 6:438–449
Ha MA, Jarvis MC, Mann JI (2000) A definition for dietary fibre. Eur J Clin Nutr 54:861–864
Heini AF, Lara-Castro C, Schneider H, Kirk KA, Considine RV, Weinsier RL (1998) Effect of hydrolyzed guar fiber on fasting and postprandal satiety and satiety hormones: a double blind, placebo-controlled trial during controlled weight loss. Int J Obes Metab Disord 22:906–909
Ibrahim OO (2009) Functional oligosaccharides: chemicals structure, manufacturing, health benefits, applications and regulations. J Food Chem Nanotechnol 4(4):65–76
Idouraine A, Hassani BZ, Claye SS, Weber CW (1995) In vitro binding capacity of various fiber sources for magnesium, zinc, and copper. J Agric Food Chem 43:1580–1584
James NB, Whistler RL (1996) Carbohydrates. In: Fennema OR (ed) Food Chemistry, 3rd edn. Marcel Dekker, New York, pp 158–205
Jenkins DJ, Wolever TM, Taylor RH, Barker H, Fielden H, Baldwin JM, Bowling AC, Newman HC, Jenkins AL, Goff DV (1981) Glycaemic index of foods: a physiological basis for carbohydrate exchange. Am J Clin Nutr 34(3):362–366
Kumar GP, Pushpa A, Prabha H (2012) A review on xylooligosaccharides. Int Res J Pharm 3 (8):71–74
LSRO (Life Sciences Research Office) (1987) Physiological effects and health consequences of dietary Fiber. Federation of American Societies for Experimental Biology, Bethesda, 236 pp
Maphosa Y, Jideani VA (2015) Dietary fiber extraction for human nutrition—a review. Food Rev Intl 32(1):98–115. https://doi.org/10.1080/87559129.2015.1057840

Moak S, Pearson N, Shin K (1987) The effect of oat and wheat bran fibers on mineral metabolism in adult males. Nutr Rep Int 36:1137

Mudgil D, Barak S (2019) Dietary fiber: classification, technological properties, and sustainable sources in properties, recovery, and applications. Academic, London, pp 27–58

Nooshkam M, Afshin B, Jooyandeh H (2018) Lactulose: properties, technofunctional food applications, and food grade delivery system. Trends Food Sci Technol. https://doi.org/10.1016/j.tifs.2018.07.028

Pasman WJ, Saris WH, Wauters MA, Westerterp-Plantenga MS (1997) Effect of one week of fibre supplementation on hunger and satiety ratings and energy intake. Appetite 29:77–87

Pinns JJ, Kaur H (2006) A review of the effects of barley β-glucans on cardiovascular and diabetic risk. Cereal Food World 51(1)

Pomeroy S, Tupper R, Chehun-Anders M, Nestel P (2001) Oats β-glucan lowers total and LDL-Cholestrol. Aust J Nutr Diet 58:1

Poutanen K, Suirti T, Aura AM, Luikkonen K, Autio K (1998) Influence of processing on the cereal dietary fibre complex: what do we know? In: Guillon F et al. (eds) Proceedings of the PROFIBRE symposium, Functional properties of non-digestible carbohydrates. Imprimeric Parentheses, Nantes, pp 66–70

Qadri OS, Younis K, Faridi SA (2017) Different approaches to Manage type-2 diabetes: special emphasis on dietary fibre. Nutr Food Sci Int J 4(3):1–4

Qiang X, Yong Lie C, Qian Bing W (2009) Health benefit application of functional oligosaccharides. Carbohydr Polym 77:435–441

Ramirez EA, Johnston DB, McAloon AJ, Singh V (2009) Enzymatic corn wet milling: engineering process and cost model. Biotechnol Biofuels 2:2

Reinhold JG (1976) Rickets in Asian immigrants. Lancet 2:1132–1133

Requena MC, Aguilar-González L, Barragán M, Cunha M, Correia J, Esquivel CCJ, Herrera RR (2016) Dietary fiber: an ingredient against obesity. Emir J Food Agr 28(8):522–530

Riedl J, Linseisen J, Hoffmann J, Wolfram G (1999) Some dietary Fibers reduce the absorption of carotenoids in women. J Nutr 129(12):2170–2176. https://doi.org/10.1093/jn/129.12.2170

Roberfroid MB (2007) Inulin-type fructans: functional food ingredients. J Nutr 137(Suppl):S2493–S2502

Roehrig KL (1988) The physiological effects of dietary fibre. A review. Food Hydrocoll 2:1–18

Ruhee RT, Suzuki K (2018) Dietary Fiber and its effect on obesity. Adv Med Res 1:1

Salehifar M, Fadaei V (2011) Comparison of some functional properties and chemical constituents of dietary fibers of Iranian rice bran extracted by chemical and enzymatic methods. Afr J Biotechnol 8:18525–18531

Shyam S, Ramdas A, Chang SK (2018) Isomaltulose: recent evidence for health benefits. J Funct Foods 48:173–178

Skyler SJ (2012) Atlas of diabetes, 4th edn. Springer, New York, pp v–vi

Sloan AE (2000) In: the top ten functional food trends. Food Technol 54:33–62

Sloan AE (2004) In: the top ten functional food trends. Food Technol 58:28–51

Sloan E (2002) In: the top 10 functional food trends. The next generation. Food Technol 56:32–57

Spiller GA (1986) CRC handbook of dietary fibre in human nutrition. CRC, Boca Raton, pp 285–286

Sridevi V, Sumathi V, Prassad MG, Murari SK (2014) Fructooligosaccharides – type prebiotic: A review. J Pharm Res 8(3):321–330

Stampfer MJ, Hu FB, Manson JE, Rimm EB, Willett WC (2000) Primary prevention of coronary heart disease in women through diet and lifestyle. N Engl J Med 343:16–22

Stevenson L, Phillips S, Sullivan KO, Walton J (2012) Wheat bran: its composition and benefits to health, European prespective. Int J Food Sci Nutr 63(4):1001–1013

Tatjana K, Terezija G, Milica K, Plestenjak A (2002) Dietary fibre content of dry and processed beans. Food Chem 80:231–235

Thed ST, Philips RD (1995) Changes of dietary fibre and starch composition of processed potato products during domestic cooking. Food Chem 52:301–304

Theuwissen E, Mensink RP (2008) Viscous soluble fibers and cardiovascular disease in the role of B-glucan, plant stanols, and oxy(phyto)sterols in managing cardiovascular risk. Maastricht: Datawyse/Universitaire Pers Maastricht. Physiol Behav 94(2):285–292
Trowell H (1972) Dietary fibre and coronary heart disease. Eur J Clin Biol Res 17:345–349
Tsai CJ, Leitzmann MF, Willett WC, Giovannucci EL (2004) Longterm intake of dietary fiber and decreased risk of cholecystectomy in women. Am J Gastroenterol 99:1364–1370
Tungland BC, Meyer D (2002) Nondigestible oligo- and polysaccharides (dietary Fiber): their physiology and role in human health and food. Compr Rev Food Sci Food Saf 1(3):90–109
Varo P, Laine R, Koivistoinen P (1983) Effect of heat treatment on dietary fibre: inter laboratory study. J Assoc Off Anal Chem 66(4):933–938
Vázquez M, Alonso J, Domínguez H, Parajó J (2000) Xylooligosaccharides: manufacture and applications. Trends Food Sci Technol 11(11): 387–393
Vidal-Valverde C, Frias J (1991) Legume processing effects on dietary fibre components. J Food Sci 56:1350–1352
Vidal-Valverde C, Frias J, Esteban R (1992) Dietary fibre in processed lentils. J Food Sci 57:1161–1163
Vieira AT, Vinolo MAR (2019) Regulation of immune cell function by short chain fatty acids and their impact on arthritis. In: Watson RR, Preedy VR (eds) Bioactive food as dietary interventions for arthritis and related inflammatory diseases, Elsevier, pp 175–188. https://doi.org/10.1016/b978-0-12-813820-5.00009-x
Vos AP, M'Rabet L, Stahl B, Boehm G, Garssen J (2007) Immunemodulatory effects and potential working mechanisms of orally applied nondigestible carbohydrates. Crit Rev Immunol 27:97–140
Warnberg J, Marcos A, Bueno G, Moreno LA (2009) Functional benefits of Psyllium supplementation. Curr Topics Nutr Res 7(2):55–64
Warrilow A, Mellor D, McKune A, Pumpa K (2018) Dietary fat, fibre, satiation, and satiety—a systematic review of acute studies. Eur J Clin Nutr. https://doi.org/10.1038/s41430-018-0295-7
Watzl B, Girrbach S, Roller M (2005) Inulin, oligofructose and immunomodulation. Br J Nutr 93 (Suppl 1):S49–S55
Wong KH, Cheung PCK (2005a) Dietary fibers from mushroom Sclerotia: 1. Preparation and physicochemical and functional properties. J Agric Food Chem 53:9395–9400
Wong KH, Cheung PCK (2005b) Dietary fibers from mushroom Sclerotia: 2. In vitro mineral binding capacity under sequential simulated physiological conditions of the human gastrointestinal tract. J Agric Food Chem 53:9401–9406
Wu AH, Tseng CC, Hankin J, Bernstein L (2007) Fiber intake and risk of adenocarcinomas of the esophagus and stomach. Cancer Causes Control 18:713–722
Younis K, Ahmad S (2015) Waste utilization of apple pomace as a source of functional ingredient in buffalo meat sausage. Cogent Food Agric 1:1119397. ISSN: 2331-1932
Younis K, Ahmad S (2018) Quality evaluation of Buffalo meat patties incorporated with apple pomace powder. Buffalo Bull 37(3):389–401. ISSN: 0125-6726
Younis K, Islam R, Jahan K, Kandu M, Ray A (2015a) Investigating the effect of Mosambi (Citrus limetta) Peel powder on physicochemical and sensory properties of cookies. Qual Assur Safety Crops Foods 8(3):393–398. ISSN 1757X
Younis K, Ahmad S (2017). Investigating the functional properties of pineapple Pomace powder and its incorporation in Buffalo meat products (Chapter 9). Plant-based natural products: Derivates and applications. Willey-Scrivener. pp. 175–192. ISBN: 9781119423898
Younis K, Ahmad S, Jahan K (2015) Health benefits and application of prebiotics in foods. J Food Proc Technol 6(433):2157–7110. https://doi.org/10.4172/2157-7110.1000433
Younis K, Islam R, Jahan K, Yousuf B, Ray A (2015b) Effect of addition of mosambi (Citrus limetta) peel powder on textural and sensory properties of papaya jam. Cogent Food Agric 1:1023675. ISSN: 2331-1932

Functional and Nutritional Aspects of Hydrocolloids and Lipids

11

Nazia Tabassum, Sweta Joshi, and Rayees Ul Islam

Abstract

The present era of increased health consciousness has led many researchers to develop food having functional aspects that help in creating a healthier society by reducing risk of several diseases as well providing beneficial physiological effects on consumption of such food. Hydrocolloids, one of the most commonly used ingredient in the food industry, has several applications, such as thickening and gelling agent in soups, salads, jellies; emulsifying and stabilizing agent in ice cream, yogurt, butter; fat replacement in meat and dairy products; clarifying agent in beer and wine; starch retrogradation inhibitor in breads; syneresis inhibitor in cheese, frozen foods; and as edible coating for fresh agricultural produce. They are very often used as a modified, edible packaging for fresh fruits and vegetables, along with lipids to enhance their shelf life while also preserving the freshness of the produce. Addition of lipids, especially essential oils, tend to increase the antimicrobial and antioxidant property of the food, thus increasing the shelf life by preserving the food from several spoilage and pathogenic bacteria and fungi. This chapter focuses on the utilization of hydrocolloids and lipids, separately and in combination, in the food industry as an ingredient, food additive, and, more importantly, as a health promoter. It will cover both the functional and nutritional aspects of hydrocolloids and lipids in foods, which has become a subject of great interest for the food researchers.

N. Tabassum (✉)
Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Joshi
Department of Food Technology, School of Interdisciplinary Science and Technology, Jamia Hamdard, New Delhi, India

R. U. Islam
Department of Bioengineering, Integral University, Lucknow, Uttar Pradesh, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_11

Keywords

Hydrocolloids · Lipids · Essential oil · Functional food · Edible coating

11.1 Introduction

During recent times, the growing desire of people to eat healthy and stay healthy has turned their inclination toward natural food products. The fast pacing world also demands convenience foods. Both of the above reasons, i.e., providing the consumers with healthy, fresh, and ready-to-eat foods, have mainly led to a rise in the hydrocolloids market. It is mainly driven by consumer preference, eating habits, research and development activities, innovation and functionality of hydrocolloids in the various food products. The various food products where hydrocolloids find an application are sauces (thickening agents), puddings (gel-forming agents), beer and wine (clarifying and foam stabilizing agents), ice cream (emulsifying agents), cheese (syneresis inhibitors), fruits and vegetables (edible film or coating formers), and sausages (binding agents and fat replacers). They are also known to inhibit crystallization in ice creams. Therefore, hydrocolloids mark as low risk and nutrient providing option that has led to an increase in their global business. According to the "Hydrocolloids Market" report, the global market for hydrocolloids was estimated at $8.8 billion in 2018 and has been projected to grow at a CAGR of 5.3% from 2018 to 2023, to reach $11.4 billion by 2023 (https://www.marketsandmarkets.com/PressReleases/hydrocolloid.asp).

Hydrocolloids are colloidal systems consisting of a diverse group of long-chain hydrophilic polymers that can readily disperse in water, partially or completely, and prone to swelling in water. This dissolution of hydrocolloids results in changed physical properties wherein the solution tends to form gels or enables thickening, coating, emulsification, and stabilization (Williams and Phillips 2003). The principal reason behind the extensive use of hydrocolloids in the food industry is their ability to bind water and modify the rheological characteristics of the product, which proves helpful in modifying and improving sensory properties (Valdez 2012). Hence, hydrocolloids could be used as an extremely significant food additive. Hydrocolloids have the potential to be used as a food additive for designing functional foods. The bigger challenge that scientists face is the design of novel nanoscale structures that could deliver hydrocolloids as a physiologically active component to provide additional health benefits to the consumer.

Moreover, hydrocolloids have also garnered attention due to their dietary aspects (Brownlee 2011; Chawla and Patil 2010). According to the latest version of the definition of dietary fiber approved by the Codex Alimentarius Commission, most food hydrocolloids could be considered as dietary fibers. Therefore, in recent years, hydrocolloids have formed an essential part of a healthy diet. The various health benefits related to the consumption of food hydrocolloids are weight management, immune regulation, improved constipation, prevention of cardiovascular diseases, and colon cancer (Li and Nie 2016). Hydrocolloids provide viscosity and play a role in developing foods with high satiating capacity. The satiety effect of hydrocolloids is related to slowing down enzyme action efficacy and/or delaying gastric emptying (Morell et al. 2014). A number of studies indicated that consumption of some specific hydrocolloids could regulate the composition of the intestinal bacterial flora, promoting good bacteria such as bifido and lactobacillus. This might lead to increased fermentative activity as well as short-chain fatty acid production (Viebke et al. 2014) since short-chain fatty acids have substantial biological effects, including the modulation of cell proliferation, apoptosis, and angiogenesis.

This chapter, therefore, focuses on the utilization of hydrocolloids and lipids, separately and in combination, in the food industry as an ingredient, food additive, and, more importantly, as a health promoter. It will cover both the functional and nutritional aspects of hydrocolloids and lipids in foods, which has become a subject of great interest for the food researchers.

The main challenge in front of a food researcher is to improve sensory properties, appearance, and shelf life of food products and also reduce their production costs or employing a new novel technology.

11.2 Hydrocolloids and Lipids: Characteristics and Functionality in the Food Sector

Hydrocolloids are basically substances that form a gel in the presence of water. This property of hydrocolloids has been majorly exploited to stabilize emulsions, suspensions, foams, or proteins and also used to inhibit ice and sugar crystal formation as well as growth. They are also often used as a processing aid in various food operations, to encapsulate and to form films due to the excellent water-binding capacity. Some of the common commercial hydrocolloids include starch, pectin, alginate, carrageenan, methylcellulose, and carboxymethylcellulose. Their origin, structure, and functionality in the food sector have been discussed below.

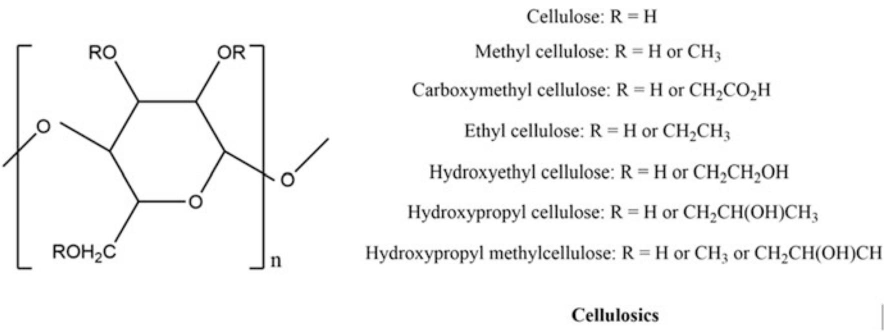
11.2.1 Cellulose and Its Derivatives

Cellulose forms the principal structural component of plant cell and is the most abundant organic polymer on Earth. It is a linear polysaccharide comprising of many glucose monosaccharides having the chemical formula $(C_6H_{10}O_5)_n$. They are highly insoluble compounds either due to the very tight packing of polymer chains (Wang et al. 2016) or due to the crystalline structure of cellulose (Lindman et al. 2010). Hence their water solubility can be increased by alkali treatment that swells the structure and reacts with chloroacetic acid, propylene oxide, or methyl chloride resulting in formation of various derivatives of cellulose, such as methylcellulose (MC), carboxymethyl cellulose (CMC), hydroxypropyl cellulose (HPC), or hydroxypropyl methylcellulose (HPMC) (Bourtoom 2008).

HPMC, approved by FDA, finds application as a gelling and stabilizing agent in the food industries due to its high permeability to water, which also limits its application for coating purposes. They exhibit excellent gas and lipid barrier properties (Sánchez-González et al. 2009). CMC, owing to its nontoxic and viscous nature, finds use as a thickening agent in various food applications and also is often used to stabilize emulsions in various products, such as ice cream.

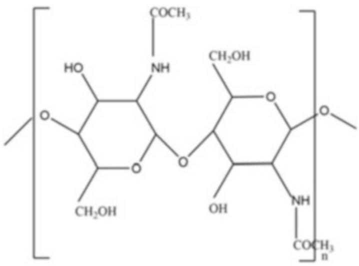
Methylcellulose (MC), most hydrophilic water-soluble cellulose derivative, is also the most economical and readily available. It is widely used as a thickener and emulsifier in food applications. MC and HPC films are efficient barriers to oxygen, carbon dioxide, and lipids but exhibit poor resistance to water vapor transport (Cazón et al. 2017) which could be handled by adding hydrophobic materials such as lipids to improve the moisture barrier properties (Villalobos et al. 2005). They also have the ability to form a thermally induced coating to cover fried products (Varela and Fiszman 2011). While MC could also be used as a coating on confectionery products due to it being a barrier to lipid migration (Nelson and Fennema 1991), HPC can be extruded into films owing to its thermoplastic properties (Bourtoom 2008) and used in whipped products as it stabilizes foams (BeMiller 2008).

Cellophane, another cellulose derivative, has high water vapor permeability, thus restricting its use in the food packaging industry as compared to synthetic polymers (Bedane et al. 2015). However, they have good mechanical properties and, when coated with nitrocellulose wax or polyvinylidene chloride (PVDC), exhibit improved barrier properties and can then be used to package bakery products, processed meat, cheese, or candies.

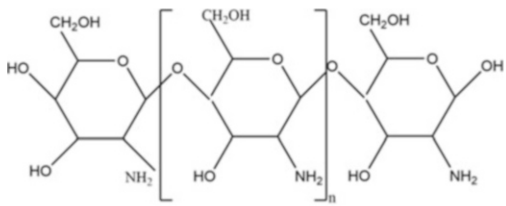


11.2.2 Chitin and Chitosan

The second most abundant naturally occurring biopolymer and whose structure is almost identical to cellulose is chitin. They are obtained from the exoskeleton of crustaceans (crab and shrimp shells) or various fungi and other biological materials. Chitosan is obtained from deacetylation of chitin in the presence of alkali. It is a nontoxic, biodegradable, and biocompatible natural polymer which is insoluble in water but soluble in various acidic solvents, like dilute hydrochloric, acetic, and formic acids. Chitosan and its derivatives can be used to form semi-permeable films and coatings that have good mechanical properties (Vargas et al. 2008) and can modify the internal atmosphere, thus delaying ripening and reducing transpiration rates in agricultural produce. Moreover, chitosan has been reported to show antifungal and antimicrobial properties (Dawson et al. 1998), which are believed to have originated from its polycationic nature. They also have the ability to absorb heavy metal ions (Chandra and Rustgi 1998), which could be useful to reduce oxidation in food catalyzed by free metals.



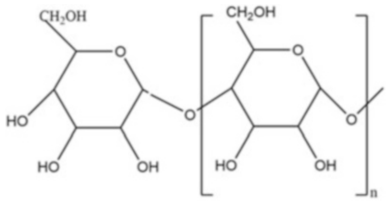
Chitin



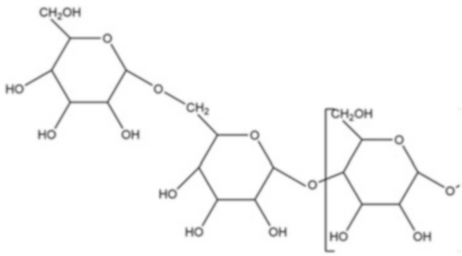
Chitosan

11.2.3 Starch

Starch is the most abundant, biodegradable polysaccharide that forms the major source of carbohydrates in the human diet. It comprises of a large number of glucose monomers joined by glycosidic bonds and consists of two polymers: a linear chained molecule, amylose, and a branched molecule termed as amylopectin (Rodríguez et al. 2006). Amylose is entirely composed of D-glucose units joined by α-1,4-glycosidic linkages, while amylopectin is also occasionally composed of α-1,6-glycosidic bonds that are responsible for the branching. Starch is insoluble in cold water or alcohol and becomes soluble in the water on heating. Starch granules tend to swell on gaining water and might burst, losing the semicrystalline structure. The amylose molecules then might leach out of the granule, forming a network that holds water and increases the mixture's viscosity. Starches are often used in the food industry because of its low cost, biodegradability, and renewability, and films formed using starch have been reported to have good mechanical properties and capability to partially or entirely replace plastic polymers (Xu et al. 2005).



Amylose

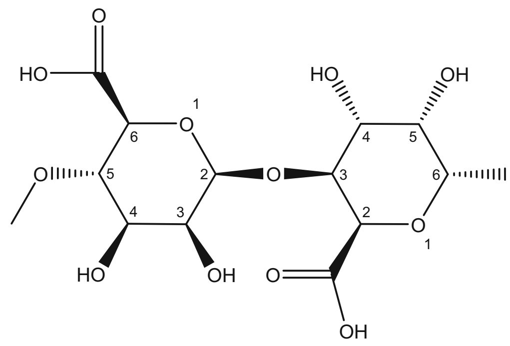


Amylopectin

11.2.4 Alginate

Alginate is the term commonly used for the salts of alginic acid, found in cell walls of brown algae of the Phaephyceae class as sodium, calcium, and magnesium salts of alginic acid. While the calcium and magnesium salts do not dissolve in water, sodium does. Hence all the alginate salts are converted into sodium salt, dissolved in water, and extracted via filtration. They are composed of D-mannuronic acid and L-guluronic acid monomers in varying degrees, molecular weight and structural arrangement (Hassan et al. 2018). Recently it has garnered huge interest as a texturizing and gelling agent in the food industry due to its various properties of thickening, gel formation, film formation, and emulsion stabilization (Draget et al. 2005). Alginate coating formation is based on the ability of alginates to react with di-valent and tri-valent cations such as calcium, ferrum, or magnesium, which are added as gelling agents (Cha and Chinnan 2004). They are also considered as a potential ingredient for a film or coating material, which might also serve as carriers for antimicrobial and antioxidant compounds (Olivas et al. 2007; Song et al. 2011).

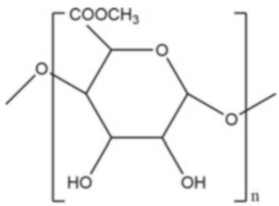
Their use at concentrations more than 10% w/w is avoided due to pourability problems resulting from a sharp increase in viscosity of the suspension (Kulkarni and Shaw 2015).



Alginic acid

11.2.5 Pectin

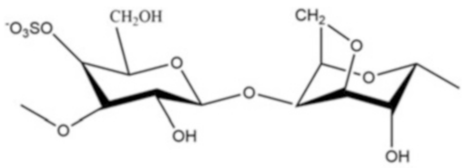
Pectin is a naturally occurring, water-soluble, complex anionic polysaccharide and most often derived from citrus fruits. On the basis of "methoxyl" content, pectin is categorized into low methoxyl pectin (LMP), having methoxyl content between 0.5% and 7% and high methoxyl pectin (HMP) with methoxyl content between 7% and 12%. The degree of methylation decisively affects the mechanism of gelation in the manufacture of fruit juices (Kang et al. 2007; Bierhalz et al. 2012). Solutions of LMP tend to gel when calcium ions are added to them in a manner similar to gelation of alginate solutions. In foods they are mainly used as thickening, gelling, or stabilizing agent in products such as fruit juices, jams, milk and yogurt drinks, and ice cream (Gutierrez-Pacheco et al. 2016), and in recent years, this gelling property of pectin has led to several researches being conducted on its use in the preparation of edible films.



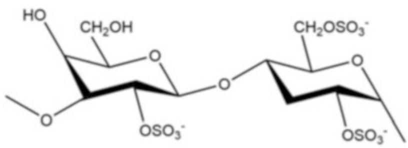
Pectin

11.2.6 Carrageenan

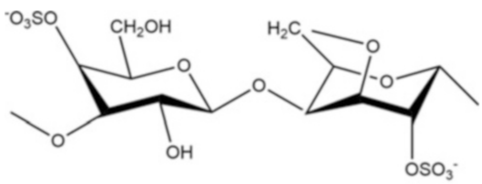
Carrageenan is a water-soluble polymer with a linear chain and partially sulfated galactans and is extracted from red seaweeds. It has been a part of traditional cooking for hundreds of years and presently is widely used in the food and pharmaceutical industry as emulsifying, stabilizing, and gelling agent. It is a complex mixture of three polymers, namely κ, λ, and ι (kappa, lambda, and iota). κ-carrageenan has excellent gel and film-forming tendency, and hence films formed from κ-carrageenan exhibit very high tensile strength (Park 1996), even higher than that of polyethylene films. Choi et al. (2005) reported that κ-carrageenan films could be used as packaging or coating material after the addition of potassium sorbate, which helps extend the shelf life of foods. λ-carrageenan does not form gels, only high viscosity solutions, and thus is commonly used as a thickening agent in the dairy industry (de Araújo et al. 2011). ι-carrageenan is also a promising film-forming material that has a strong affinity toward milk proteins and is thus widely used in the dairy industry (Karbowiak et al. 2006).



kappa carrageenan



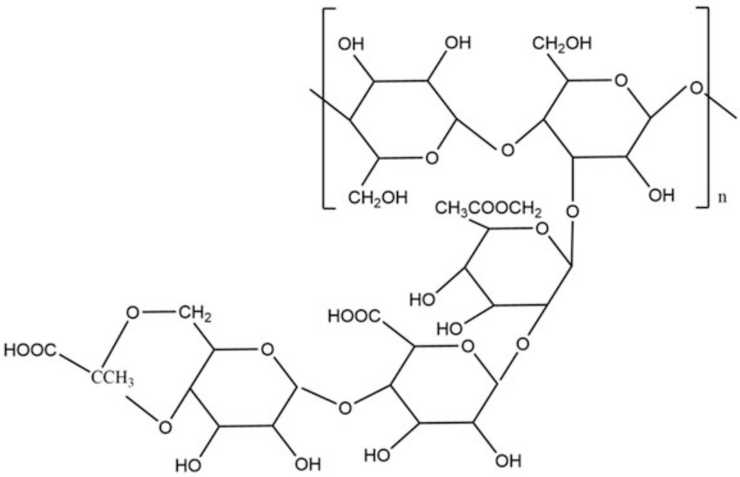
lambda carrageenan



iota carrageenan

11.2.7 Xanthan

After dextran, xanthan is the second microbial polysaccharide commercialized and is completely soluble in hot as well as cold water. They are commercially known as xanthan gum and are produced from *Xanthomonas campestris*. When in contact with water, it hydrates quickly and results in very high viscous solutions even at low concentrations due to their excellent water-binding capacity. The solutions thus formed remain unaffected by the change in temperature, pH, or salt concentration. This property makes xanthan a very effective thickener and stabilizer. Xanthan gum solutions are highly pseudoplastic, i.e., even after high shear rates, the initial viscosity is rebuilt immediately. This property enhances the sensory qualities, such as mouthfeel and flavor release in food. Xanthan available commercially may differ based on particle size, viscosity grades, dispersibility rate, pseudo-plasticity, and different hydrating time due to the different strains of organisms used for their production and also the different growth conditions (BeMiller 2008).



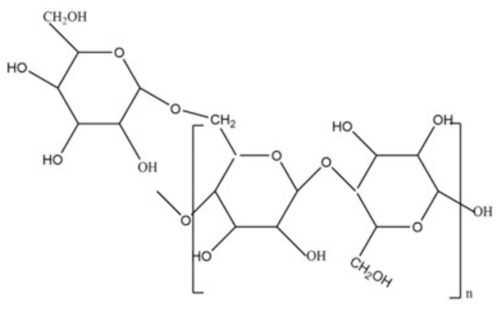
Xanthan gum

11.2.8 Gum Arabic

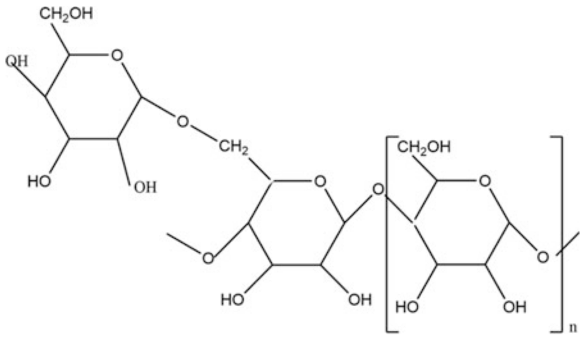
Gum arabic is a natural gum obtained from various species of acacia trees. The main source of commercial gum arabic is *Acacia senegal*. Gum arabic dissolves in cold water and exhibits very low viscosity even at higher concentrations (30% of gum arabic has a lower viscosity than 1% xanthan gum or CMC at low shear rates) (Philips and Williams 2000). It exhibits Newtonian behavior, unlike most other hydrocolloids, with its viscosity being shear-rate-independent. Above properties of gum arabic make it unsuitable as a thickening agent but, when used in an appropriate amount, may be included in gluten-free products to obtain good and improved quality attributes (BeMiller 2008).

11.2.9 Galactomannans (Guar Gum, Locust Bean Gum, Tara Gum, Cassia Gum)

Galactomannans are polysaccharides composed of D-mannose and D-galactose with varying mannose to galactose ratio (M/G). They are commercially isolated from the seeds of guar, carob, tara, or fenugreek plants. Due to the differing M/G ratio, galactomannans are observed to interact synergistically making thick, viscous products than either of them alone. Guar gum is a neutral polysaccharide, and its solutions are little affected by ions or pH. It exhibits a synergistic effect when used with agar, xanthan, or κ-carrageenan, resulting in very high viscosities. It has often been used in the confectionery industry, as an emulsifier for flavor oils for incorporation in beverages (Williams and Phillips 2003). Locust bean gum significantly improves texture, transparency, and gel strength, and prevents syneresis when used in combination with carrageenans. It has commonly been used in various food products, such as ice cream, cheese, ready-to-eat meals, sauces, salad dressing, and bakery products. Tara and cassia gum are the less exploited hydrocolloids, and their use and acceptability as a food ingredient is still a matter of debate. Guar gum is most extensively used galactomannan, mainly due to its low and stable price.



Guar Gum



Locust bean gum

11.2.10 Lipids

Lipids constitute a large number of naturally occurring organic compounds that are nonpolar, hydrophobic substances that are insoluble in water but find solubility in nonpolar organic solvents such as chloroform, ether, acetone, and benzene. Lipid-based coatings have been in use for the past several centuries for wax coating of fruits or coating of confectionery products (Hardenburg 1967; Kester and Fennema 1986). They are most preferred due to their hydrophobic property, which makes them excellent moisture barriers and also reduces respiration (Dhall 2013), thus prolonging the shelf life of coated products. Lipids that have most commonly and effectively been used in coating formulations are paraffin wax, beeswax, carnauba wax, vegetable and mineral oil, surfactants, and acetylated monoglycerides (Kester and Fennema 1986). Lipid coating primarily blocks all kinds of moisture transfer due to their low polarity while forming thick, opaque, and brittle films. They also provide gloss, thus enhancing the visual appeal of the coated products. Application of lipid-based films and coatings into food has largely been limited due to their weak mechanical strength and poor film-forming ability. Therefore, they must be used in combination with film-forming agents such as proteins and polysaccharides as they might interfere with the polymer chain-to-chain interactions and provide better flexibility to the films and coatings. Natural wax such as carnauba wax has been used in combination with cassava starch and glycerol for coating of apple slices, and the coating has been reported to exhibit improved mechanical properties, and barrier to gas and moisture migration (Chiumarelli and Hubinger 2014).

11.2.11 Essential Oil

Essential oils are lipidic substances extracted from plants with strong antimicrobial and antioxidant properties. They capture or retain plants essence from which they are extracted making them unique aromatic compounds. This specific characteristic of EOs limits its use in food preservation due to their intense aroma which very often dominates the original aroma of the food in which they are incorporated. The high application cost is another drawback that restricts their use. Interestingly it has been observed that doses of EOs could be reduced by incorporating them into the formulation of edible coatings while still maintaining their effectiveness (Perdones et al. 2012). This approach would also reduce the application cost. In one of the studies, fresh-cut pineapple was preserved by Azarakhsh et al. (2014) using alginate-based edible coating incorporated with lemongrass essential oil which reduced the yeast and mold counts and total plate counts during the storage period. Similar studies have been conducted using various essential oils such as thyme, oregano, basil, citral, and many others to preserve fruits and vegetables.

11.3 Potential Application in the Food Industry

Hydrocolloids have found various applications as ingredient in the food industry. Few of the applications include, as a thickening and gelling agent in soups, salads, sauces, and jellies (Krystyjan et al. 2012; Kiani et al. 2010); emulsifying and stabilizing agent in ice cream, yogurt, butter; fat replacement in meat and dairy products (Pinero et al. 2008); raw material of edible coating to improve shelf life and quality characteristics of fresh fruits and vegetables. They often act as carrier for antimicrobial or antioxidant agents; such as essential oils that tend to increase shelf life of food by preserving them from several spoilage and pathogenic bacteria and fungi. Various applications of hydrocolloids in different food products have been discussed in brief in Table 11.1.

11.3.1 Thickening Agent

Hydrocolloids are most frequently used as a thickening agent in several food preparations. This thickening property of hydrocolloids basically confers to increased viscosity which involves nonspecific entanglement of conformationally disordered polymer chains (Philips et al. 1986). Thickening is believed to occur above a critical concentration known as overlap concentration (C∗). The hydrocolloid dispersions exhibit Newtonian behavior below this overlap concentration (C∗), i.e., viscosity is independent of the rate of shear and non-Newtonian behavior above this concentration (Philips and Williams 2000). The thickening effect produced by the hydrocolloids depends on the type of hydrocolloid used, its concentration, pH, and temperature of the food system in which it is incorporated. Some commonly

Table 11.1 Various application of hydrocolloids in different foods

Function	Food product
Thickening agent	Soups, gravies, sauces, salad dressings, and toppings
Gelling agent	Puddings and jellies
Emulsifying agent	Yogurt, ice cream, and butter
Coating agent	Confectionery, fried foods, fruits, and vegetables
Encapsulating agent	Powdered flavors or some oils
Fat replacer	Meat and dairy products
Crystallization inhibitor	Ice cream and sugar syrups
Starch retrogradation inhibitors	Breads and batters
Syneresis inhibitors	Cheese and frozen foods
Suspending agents	Chocolate milk
Water-binding agents	Gluten-free foods
Foam stabilizer	Beer and whipped toppings
Flocculating agent	Wine
Bioplastics	Food packaging

used thickening agents are starch, xanthan, CMC, HPMS, or galactomannans such as guar gum and locust bean gum.

Xanthan gum exhibits very high low-shear viscosity, high shear thinning, and maintains viscosity in the presence of electrolyte for a wide range of temperature and pH. CMC exhibits high viscosity but gets reduced at low pH or on the addition of electrolytes. On the other hand, MC and HPMC increase viscosity with temperature but are independent of pH or electrolytes. While gum arabic is a low viscosity gum and exhibits near Newtonian behavior, shear thinning at low shear rates, galactomannans (guar and locust bean gum) exhibit very high low-shear viscosity and strong shear thinning. Although they are not influenced by the presence of electrolytes, they do get degraded at high and low pH and lose viscosity when subjected to high temperatures. Most common food item where the thickening property of hydrocolloids are put to use to control the viscosity is ketchup, and most commonly used hydrocolloid as a thickener is a starch due to its low cost and non-alteration in the taste of food product when used at low concentrations of 2–5% (Saha and Bhattacharya 2010) (Table 11.2).

11.3.2 Gelling Agent

Apart from thickening the food, hydrocolloids also possess the ability to form gels. A gel is a colloidal dispersion where a solid matrix is a continuous phase while a liquid is a discontinuous phase (Saha and Bhattacharya 2010). It forms a three-dimensional network that interlaces suspended particles, thereby restricting movement in the dispersing medium. On hydration, these gelling agents undergo a high degree of cross-linking resulting in an increase in viscosity. In rheological terms, a gel is a viscoelastic system with a "storage modulus" (G') larger than the "loss

Table 11.2 Application of hydrocolloids as thickeners in food

Hydrocolloid	Food products	Function	References
Xanthan	Cassava wheat flour dough and bread, gluten-free bread based on maize	Increases crumb softness, open crumb structure, better sensory acceptability	Shittu et al. (2009), Hager and Arendt (2013)
Xanthan, guar gum	Infrared-microwave oven baked breads	Increases specific volume and porosity, reduces hardness of breads and dielectric properties of dough	Keskin et al. (2007)
Carboxymethyl cellulose (CMC)	Cassava starch-based films	Improves tensile strength, reduces elongation break of weak and brittle cassava starch films	Tongdeesoontorn et al. (2011)
Hydroxypropylmethyl cellulose (HPMC)	Wheat bread, maize, rice, teff, buckwheat bread	Improves fresh bread quality, delays staling, decreases hardening rate of bread crumb, retards amylopectin retrogradation	Barcenas and Rosell (2005), Hager and Arendt (2013)
Carboxymethyl cellulose (CMC), xanthan, guar gum	Ketchup	Stabilizes consistency, behaves as non-Newtonian, shear thinning fluid in a temperature range of 25–55 °C	Koocheki et al. (2009)
Carboxymethyl cellulose (CMC), Konjac glucomannan	Emulsion, emulsion films	Enhances emulsion stability during drying, improves barrier and mechanical properties of films	Cheng et al. (2008)
Gum arabic	Commercial beverages	Enhances the stability of natural colorants (anthocyanin)	Chung et al. (2016)
Galactomannans (guar gum, locust bean gum, tara gum)	Rice cake batter, edible films or coatings	High shear thinning, improves stability and quality of food products applied on	Turabi et al. (2008), Cerqueira et al. 2011

modulus” (G″) (Li and Nie 2016). Few gel-forming hydrocolloids include agar, pectin, alginate, carrageenan, gelatin, modified starch, and methylcellulose. They are commonly used in food products like jams, jellies, puddings, restructured foods and bakery products (Saha and Bhattacharya 2010; Soultani et al. 2014).

Some hydrocolloids exhibit a reversible transition from sol to gel by a change in temperature. This sol–gel transition (Kiani et al. 2010; Moschakis et al. 2014) mainly depends on the nature of secondary or non-covalent molecular forces such as hydrogen bonds and hydrophobic interaction. Syneresis is a common undesirable phenomenon occurring in some products such as jelly due to shrinkage of gel structure formed by cross-linking of pectin, carrageenan, or alginate by calcium ions. On the contrary, syneresis may prove to be beneficial in cheese production (Mateva et al. 2013). Practically synergy can be built by a combination of other hydrocolloids with gums that form brittle gels, like the addition of locust bean gum into κ-carrageenan-based gel, leading to a more elastic and transparent gel (Nussinovitch 1997). Also, superior food gels can be obtained by combining gelling and non-gelling agents. For example, the addition of gum arabic to agar-based marshmallows to soften their texture or addition of CMC to alginate desserts to improve their resistance to textural deterioration in the freezing and thawing cycles (Nussinovitch and Hirashima 2014). Similarly, the texture of several products such as marshmallows, pie fillings, and meringues can be improved by the addition of non-gelling hydrocolloids (Li and Nie 2016).

11.3.3 Emulsifying Agent

In an emulsion system, emulsifier promotes emulsion formation and maintains uniformity of the mixing system by reducing the interfacial tension between two phases, and stabilizer confers long-time stability of the emulsion (Dickinson 2003).

Hydrocolloids are used to improve texture, body, and gelation of milk-based formulations like flavored milk or yogurt drinks (Li and Nie 2016). They also help to increase the shelf life of acidified fruit milk drinks and chocolate milk and prevent their wheying or settling of dispersed particles or creaming or flocculation of the emulsion droplets.

Most commonly used hydrocolloid emulsifier is gum arabic, which finds wide application in soft drinks for emulsifying flavor oils at low pH and high ionic strength as well as in the presence of beverage coloring agents (Nakauma et al. 2008). Galactomannans, modified starches, and some cellulose derivative pectins are few other hydrocolloid emulsifiers used in food industry.

11.3.4 Surface Activity and Emulsification Property

Rigid hydrocolloids are commonly not considered as classical emulsifiers due to the lack of a flexible molecular structure but fits in as stabilizers due to their hydrophilicity, high molecular weight, and gelation behavior.

The traditional viewpoint is that excellent emulsifiers such as protein emulsifiers possess flexible molecular structures which result in rapid adsorption and rearrangement at the interface to give a coherent macromolecular protective layer. It means that rigid hydrocolloids are not considered as classical emulsifiers but fit into stabilizers due to their hydrophilicity, high molecular weight, and gelation behavior. Nevertheless, a few hydrocolloids are well recognized to adsorb on oil–water interfaces and to stabilize emulsions. They retard precipitation of dispersed solid particles and coalescence of oil droplets, decrease creaming rates of oil droplets and foams, and preclude syneresis of gel systems containing oils as well as the aggregation of dispersed particles. Additionally, in comparison with protein emulsifiers, the large molecular size and predominant hydrophilicity of a hydrocolloid emulsifier leads to the formation of a thicker stabilizing layer which is capable of protecting droplets against aggregation over adverse conditions, such as the addition of calcium salts and thermal shock treatment (Chanamai and McClements 2002).

Typically, commercial pectins from citrus peel are not employed as emulsifiers irrespective of the degree of esterification. Highly acetylated pectin from sugar beet has been reported to exhibit surface activity, while pectins from citrus fruits and apples with a low acetyl content ($<0.8\%$) also possess good surface activity (Dickinson 2003). Good stabilization can also be achieved with various surface-active derivatives of cellulose such as hydroxypropyl (methyl) cellulose (Dickinson 2009).

11.3.5 Fat-Replacing Agents

Fats tend to provide desirable taste, texture, and appearance, when present in foods. However, their negative impact on human health has prompted food industries to develop food products utilizing reduced versions of fat (Hoefkens et al. 2011; Weiss et al. 2010). Few emulsion-based food products such as, ice cream, frozen desserts, puddings, sauces, and salad dressings have a relative high fat content and therefore require effective measures to reduce it. However, this reduction of fat might lead to further reduction in desirable sensory qualities. Therefore, it becomes essential to design food products that possess not only reduced fat content but also sensory qualities similar to those of their full-fat counterparts. This can be achieved by utilization of fat substitutes or fat replacers.

Fat replacer is an ingredient that replaces some or all the functions of fat and may or may not provide nutritional value (Miraglio 1995). Some hydrocolloid-based fat replacers include pectin, inulin, guargum, xanthan gum, gum tragacanth, locust bena gum, κ-carrageenan, and sodium alginate (Aziznia et al. 2008).

11.3.6 Bioplastics for Food Packaging

Food packaging for years has utilized the nondegradable version of plastics but with recent increase in ecological consciousness, bioplastics has proven to be a good substitute for the traditional plastic.

Cellulose is a biodegradable hydrocolloid that can form cellophane films. Among the several cellulose derivatives having excellent film-forming property, cellulose acetate is the most commonly used for food packaging, especially of fresh produce and baked goods. Several large corporations such as Wal-Mart, Birkel, etc. use cellulose films to package pasta, potato chips, and fruit.

Starch is another hydrocolloid that is easily biodegradable and forms an important component of bioplastics. On industrial level, they have been utilized for extrusion, fil blowing, blow molding, and injection molding. Famous retail stores, such as Marks & Spencer Group, has used cornstarch trays in milk chocolates, while Iper has used it in organic tomato packaging. Moreover, hydrocolloid mixture such as starch and cellulose, pectin and chitosan, pectin and gelatin, gelatin and sodium alginate can be used to produce bioplastics.

11.4 Health Benefits

The increasing health consciousness among consumers has led to the demand of low-fat foods enriched with fiber. Dietary fiber mainly comprises of polysaccharides that are resistant to human endogenous enzymes and generally considered as structural components of cereals and vegetables. There is a common belief throughout the world that natural foods containing fiber provides for a healthy lifestyle. Hydrocolloids with good textural and fiber characteristics may help in maintaining a healthy colon.

There has been an alarming growth in chronic diseases mainly due to the overconsumption of high-calorie and high-fat foods. Therefore, a need arises to decrease the consumption of sugar in the diet and simultaneously increase the uptake of dietary fibers. Many years ago, it was reported that diet containing guar gum prolonged the transit time from mouth to cecum, delayed gastric emptying, slowed down the increase in postprandial glycemia and provide benefits to colonic function (Cummings et al. 1978; Jenkins et al. 1975). However, the high viscosity of guar gum proves a deterrent feature in terms of sensory attributes (Buriti et al. 2014). Researchers have now reported a wide range of hydrocolloids such as pectin, alginate, starch, gum arabic, pectin, psyllium, chitosan, carrageenan, and many more to possess nutritive, textural, and health benefits. The various health benefits associated with hydrocolloids use include appetite regulation, improved bowel movements and prevention of coronary heart diseases, colon cancer, and type 2 diabetes mellitus (Hu et al. 2011).

11.5 Future Prospects

With the fast-moving life, demand for ready-to-eat meals, and increased health consciousness among consumers, use of hydrocolloids in the food sector will only increase in the future. Introduction of new hydrocolloids or synergistic use of existing hydrocolloids to improve thickening and gelling characteristics could be exploited. Though this exercise might face several hurdles due to the high costs involved in obtaining food approval. To counter this problem, food industries could use combinations of hydrocolloids that have already gained approval for use as a food additive in a synergistic manner. Since 1970s, synergy between agarose, carrageenan, and xanthan with stiff linear polymers such as galactomannans has been known, but recent years have seen growing interest in pectin-alginate combinations that form gels with improved characteristics by calcium ion cross-linking.

Another aspect that can become focus for future research is the solubility of hydrocolloids in food systems. Some hydrocolloids are known to be partially or completely soluble in water. If ways or technologies could be devised to increase their solubility, making them instant soluble, their usage could further be improved. Therefore, researchers need to take extra steps to develop hydrocolloids combination with improved textural characteristics, thus paving way for increased market for hydrocolloids. Moreover, the regulatory and social factor also dampens the efforts of these researchers. Regulatory issues such as levels of use and application in various foods and social issues such as vegetarianism, halal, and kosher have further impacted the hydrocolloid market. Therefore, there is a need to aware the consumers of the excellent properties of hydrocolloids when used as an additive in food as the consumer perceptions and resulting actions determine the commercial future of any food ingredient.

References

Azarakhsh N, Osman A, Ghazali HM, Tan CP, Mohd Adzahan N (2014) Lemongrass essential oil incorporated into alginate-based edible coating for shelf-life extension and quality retention of fresh-cut pineapple. Postharvest Biol Technol 88:1–7

Aziznia S, Khosrowshahi A, Madadlou A, Rahimi J (2008) Whey protein concentrate and gum tragacanth as fat replacers in nonfat yogurt: chemical, physical, and microstructural properties. J Dairy Sci 91(7):2545–2552

Barcenas ME, Rosell CM (2005) Effect of HPMC addition on the microstructure, quality and aging of wheat bread. Food Hydrocoll 19(6):1037–1043

Bedane AH, Eić M, Farmahini-Farahani M, Xiao H (2015) Water vapor transport properties of regenerated cellulose and nanofibrillated cellulose films. J Membr Sci 493:46–57

BeMiller JN (2008) Hydrocolloids. In: Gluten-free cereal products and beverages. Academic, London, pp 203–215

Bierhalz ACK, da Silva MA, Kieckbusch TG (2012) Natamycin release from alginate/pectin films for food packaging applications. J Food Eng 110(1):18–25

Bourtoom T (2008) Edible films and coatings: characteristics and properties. Int Food Res J 15 (3):237–248

Brownlee IA (2011) The physiological roles of dietary fibre. Food Hydrocoll 25(2):238–250

Buriti FC, dos Santos KM, Sombra VG, Maciel JS, Sá DMT, Salles HO, Oliveira G, de Paula RC, Feitosa JP, Moreira ACM, Moreira RA (2014) Characterisation of partially hydrolysed galactomannan from Caesalpinia pulcherrima seeds as a potential dietary fibre. Food Hydrocoll 35:512–521

Cazón P, Velazquez G, Ramírez JA, Vázquez M (2017) Polysaccharide-based films and coatings for food packaging: A review. Food Hydrocoll 68:136–148

Cerqueira MA, Bourbon AI, Pinheiro AC, Martins JT, Souza BWS, Teixeira JA, Vicente AA (2011) Galactomannans use in the development of edible films/coatings for food applications. Trends Food Sci Technol 22(12):662–671

Cha DS, Chinnan MS (2004) Biopolymer-based antimicrobial packaging: a review. Crit Rev Food Sci Nutr 44(4):223–237

Chanamai RADJM, McClements DJ (2002) Comparison of gum arabic, modified starch, and whey protein isolate as emulsifiers: influence of pH, CaCl2 and temperature. J Food Sci 67 (1):120–125

Chandra R, Rustgi R (1998) Biodegradable polymers. Prog Polym Sci 23:1273–1335

Chawla RPGR, Patil GR (2010) Soluble dietary fiber. Compr Rev Food Sci Food Saf 9(2):178–196

Cheng LH, Karim AA, Seow CC (2008) Characterisation of composite films made of konjac glucomannan (KGM), carboxymethyl cellulose (CMC) and lipid. Food Chem 107(1):411–418

Chiumarelli M, Hubinger MD (2014) Evaluation of edible films and coatings formulated with cassava starch, glycerol, carnauba wax and stearic acid. Food Hydrocoll 38:20–27

Choi JH, Choi WY, Cha DS, Chinnan MJ, Park HJ, Lee DS, Park JM (2005) Diffusivity of potassium sorbate in κ-carrageenan based antimicrobial film. LWT—Food Science and Technology 38(4):417–423

Chung C, Rojanasasithara T, Mutilangi W, McClements DJ (2016) Enhancement of colour stability of anthocyanins in model beverages by gum arabic addition. Food Chem 201:14–22

Cummings JH, Branch W, Jenkins DJA, Southgate DAT, Houston H, James WPT (1978) Colonic response to dietary fibre from carrot, cabbage, apple, bran, and guar gum. Lancet 311(8054):5–9

Dawson PL, Han IY, Orr RV. Acton JC (1998) Chitosan coatings to inhibit bacterial growth on chicken drumsticks. In: Proceedings of the 44th International Conference of Meat Science and Technology, Barcelona, Spain, pp 458–462

de Araújo IWF, Vanderlei EDSO, Rodrigues JAG, Coura CO, Quinderé ALG, Fontes BP, de Queiroz INL, Jorge RJB, Bezerra MM, Rodrigues e Silva AA, Chaves HV, HSA M, RCM d P, NMB B (2011) Effects of a sulfated polysaccharide isolated from the red seaweed Solieria filiformis on models of nociception and inflammation. Carbohydr Polym 86(3):1207–1215

Dhall RK (2013) Advances in edible coatings for fresh fruits and vegetables: A review. Crit Rev Food Sci Nutr 53(5):435–450

Dickinson E (2003) Hydrocolloids at interfaces and the influence on the properties of dispersed systems. Food Hydrocoll 17(1):25–39

Dickinson E (2009) Hydrocolloids as emulsifiers and emulsion stabilizers. Food Hydrocoll 23 (6):1473–1482

Draget KI, Smidsrød O, Skjåk-Broek G (2005) Polysaccharides and polyamides in the food industry: properties, production, and patents. Wiley, Hoboken, pp 1–30

Gutierrez-Pacheco MM, Ortega-Ramirez LA, Cruz-Valenzuela MR, Silva-Espinoza BA, Gonzalez-Aguilar GA, Ayala-Zavala JF (2016) Chapter 50- combinational approaches for antimicrobial packaging: pectin and cinnamon leaf oil. In: Antimicrobial food packaging. Academic Press, San Diego, pp 609–617

Hager AS, Arendt EK (2013) Influence of hydroxypropylmethylcellulose (HPMC), xanthan gum and their combination on loaf specific volume, crumb hardness and crumb grain characteristics of gluten-free breads based on rice, maize, teff and buckwheat. Food Hydrocoll 32(1):195–203

Hardenburg RE (1967) Wax and related coatings for horticulture products, a bibliography. Agric Res Serv Bull

Hassan B, Chatha SAS, Hussain AI, Zia KM, Akhtar N (2018) Recent advances on polysaccharides, lipids and protein based edible films and coatings: A review. Int J Biol Macromol 109:1095–1107

Hoefkens C, Verbeke W, Van Camp J (2011) European consumers' perceived importance of qualifying and disqualifying nutrients in food choices. Food Qual Prefer 22(6):550–558

Hu XZ, Xing XH, Zhang ZM, Wu RQ, Guo Q, Cui SW, Wang Q (2011) Antioxidant effects of Artemis sphaerocephala Krasch. Gum, on streptozotocin-induced type 2 diabetic rats. Food Hydrocoll 25(2):207–213

Jenkins DA, Newton C, Leeds A, Cummings J (1975) Effect of pectin, guar gum, and wheat fibre on serum-cholesterol. Lancet 305(7916):1116–1117

Kang HJ, Jo C, Kwon JH, Kim JH, Chung HJ, Byun MW (2007) Effect of a pectin-based edible coating containing green tea powder on the quality of irradiated pork patty. Food Control 18 (5):430–435

Karbowiak T, Debeaufort F, Champion D, Voilley A (2006) Wetting properties at the surface of iota-carrageenan-based edible films. J Colloid Interface Sci 294(2):400–410

Keskin SO, Sumnu G, Sahin S (2007) A study on the effects of different gums on dielectric properties and quality of breads baked in infrared-microwave combination oven. Eur Food Res Technol 224(3):329–334
Kester JJ, Fennema OR (1986) Edible films and coatings: a review. Food Technol (USA) 40 (12):47–59
Kiani H, Mousavi ME, Razavi H, Morris ER (2010) Effect of gellan, alone and in combination with high-methoxy pectin, on the structure and stability of dough, a yogurt-based Iranian drink. Food Hydrocoll 24(8):744–754
Koocheki A, Ghandi A, Razavi SM, Mortazavi SA, Vasiljevic T (2009) The rheological properties of ketchup as a function of different hydrocolloids and temperature. Int J Food Sci Technol 44 (3):596–602
Krystyjan M, Sikora M, Adamczyk G, Tomasik P (2012) Caramel sauces thickened with combinations of potato starch and xanthan gum. J Food Eng 112(1–2):22–28
Kulkarni VS, Shaw C (2015) Essential chemistry for formulators of semisolid and liquid dosages. Academic, London
Li JM, Nie SP (2016) The functional and nutritional aspects of hydrocolloids in foods. Food Hydrocoll 53:46–61
Lindman B, Karlström G, Stigsson L (2010) On the mechanism of dissolution of cellulose. J Mol Liq 156(1):76–81
Mateva N, Srbinovska S, Nikola P, Eftimova E (2013) Factors affecting the syneresis and coagulation in ultra-filtered cheese. J Hygienic Eng Design 3:48–53
Miraglio AM (1995) Nutrient substitutes and their energy values in fat substitutes and replacers. Am J Clin Nutr 62(5):1175S–1179S
Morell P, Fiszman SM, Varela P, Hernando I (2014) Hydrocolloids for enhancing satiety: relating oral digestion to rheology, structure and sensory perception. Food Hydrocoll 41:343–353
Moschakis T, Lazaridou A, Biliaderis CG (2014) A micro-and macro-scale approach to probe the dynamics of sol–gel transition in cereal β-glucan solutions varying in molecular characteristics. Food Hydrocoll 42:81–91
Nakauma M, Funami T, Noda S, Ishihara S, Al-Assaf S, Nishinari K, Phillips GO (2008) Comparison of sugar beet pectin, soybean soluble polysaccharide, and gum arabic as food emulsifiers. 1. Effect of concentration, pH, and salts on the emulsifying properties. Food Hydrocoll 22(7):1254–1267
Nelson KL, Fennema OR (1991) Methylcellulose films to prevent lipid migration in confectionery products. J Food Sci 56(2):504–509
Nussinovitch A, Hirashima M (2014) Cooking innovations: using hydrocolloids for thickening, gelling, and emulsification. CRC, Boca Raton
Nussinovitch A (1997) Hydrocolloid applications: gum technology in the food and other industries. In: 134–137. Blackie Academic, London
Olivas GI, Mattinson DS, Barbosa-Cánovas GV (2007) Alginate coatings for preservation of minimally processed 'Gala' apples. Postharvest Biol Technol 45(1):89–96
Park HJ (1996) Gas and mechanical barrier properties of carrageenan-based biopolymer films. Korean J Food Sci Indust 29(2):47–53
Perdones A, Sánchez-González L, Chiralt A, Vargas M (2012) Effect of chitosan–lemon essential oil coatings on storage-keeping quality of strawberry. Postharvest Biol Technol 70:32–41
Philips GO, Wedlock DJ, Williams PA (1986) Molecular origin of hydrocolloid functionality. In: Philips GO, Williams PA, Wedlock DJ (eds) Gums and stabilizers for the food industry, vol 3. IRL Press, Oxford, pp 3–5
Philips GO, Williams PA Introduction to food hydrocolloids. In: Handbook of hydrocolloids. Woodhead, New York, 2000 1–19
Pinero MP, Parra K, Huerta-Leidenz N, De Moreno LA, Ferrer M, Araujo S, Barboza Y (2008) Effect of oat's soluble fibre (β-glucan) as a fat replacer on physical, chemical, microbiological and sensory properties of low-fat beef patties. Meat Sci 80(3):675–680

Rodríguez M, Oses J, Ziani K, Mate JI (2006) Combined effect of plasticizers and surfactants on the physical properties of starch based edible films. Food Res Int 39(8):840–846
Saha D, Bhattacharya S (2010) Hydrocolloids as thickening and gelling agents in food: a critical review. J Food Sci Technol 47(6):587–597
Sánchez-González L, Vargas M, González-Martínez C, Chiralt A, Cháfer M (2009) Characterization of edible films based on hydroxypropylmethylcellulose and tea tree essential oil. Food Hydrocoll 23(8):2102–2109
Shittu TA, Aminu RA, Abulude EO (2009) Functional effects of xanthan gum on composite cassava-wheat dough and bread. Food Hydrocoll 23(8):2254–2260
Song Y, Liu L, Shen H, You J, Luo Y (2011) Effect of sodium alginate-based edible coating containing different anti-oxidants on quality and shelf life of refrigerated bream (Megalobrama amblycephala). Food Control 22(3–4):608–615
Soultani G, Evageliou V, Koutelidakis AE, Kapsokefalou M, Komaitis M (2014) The effect of pectin and other constituents on the antioxidant activity of tea. Food Hydrocoll 35:727–732
Tongdeesoontorn, W., Mauer, L.J., Wongruong, S., Sriburi, P. and Rachtanapun, P., 2011. Effect of carboxymethyl cellulose concentration on physical properties of biodegradable cassava starch-based films. *Chemistry Central Journal*, *5*(1), p. 6
Turabi E, Sumnu G, Sahin S (2008) Rheological properties and quality of rice cakes formulated with different gums and an emulsifier blend. Food Hydrocoll 22(2):305–312
Valdez B (ed) (2012) Food industrial processes: methods and equipment. BoD–Books on Demand
Varela P, Fiszman SM (2011) Hydrocolloids in fried foods. A review Food Hydrocolloids 25 (8):1801–1812
Vargas M, Pastor C, Chiralt A, McClements DJ, Gonzalez-Martinez C (2008) Recent advances in edible coatings for fresh and minimally processed fruits. Crit Rev Food Sci Nutr 48(6):496–511
Viebke C, Al-Assaf S, Phillips GO (2014) Food hydrocolloids and health claims. Bioact Carbohydr Diet Fibre 4(2):101–114
Villalobos R, Chanona J, Hernández P, Gutiérrez G, Chiralt A (2005) Gloss and transparency of hydroxypropyl methylcellulose films containing surfactants as affected by their microstructure. Food Hydrocoll 19(1):53–61
Wang S, Lu A, Zhang L (2016) Recent advances in regenerated cellulose materials. Prog Polym Sci 53:169–206
Weiss J, Gibis M, Schuh V, Salminen H (2010) Advances in ingredient and processing systems for meat and meat products. Meat Sci 86(1):196–213
Williams PA, Phillips GO (2003) The use of hydrocolloids to improve food texture. In: Texture in food. Woodhead, pp 251–274
Xu XY, Kim KM, Hanna MA, Nag D (2005) Chitosan-starch composite film: preparation and characterization. Ind Crop Prod 21(2):185–192

Future Prospects of Fruit and Vegetable-Based Functional Foods

12

Ovais Shafiq Qadri, Kaiser Younis, and Tawheeda Yasin

Abstract

Fruits and vegetables are mainly composed of water and carbohydrates. Although not a primary source of energy, the carbohydrates found across fruits and vegetables vary widely and some of them possess health benefits, for instance dietary fibre. In our diet, fruits and vegetables are a source of important micronutrients. Many of the constituents found in fruits and vegetables have functional properties and help people live a healthier life. The presence of functional ingredients in fruits and vegetables makes them one of the potential raw material for formulation of functional foods. Moreover, the consumer perception towards consumption of fruits and vegetables is directly related to better health and people are familiar with the sensory attributes of fruits and vegetables. In addition, huge quantity of residue is generated during the preparation and processing of fruits and vegetables. Majority of this residue, however, very rich in bioactive compounds, is wasted. The utilization of these residues in formulation of functional foods has been a widely researched area in food science. Numerous products are available commercially based on the fruit and vegetable industry residue and are extensively consumed by people. The scope of such products is on a rise owing to the consumer sensitivity regarding better health being related to healthy and balanced diet. In this chapter, the technology and prospect of fruit and vegetable-based functional foods are discussed.

O. S. Qadri (✉)
Department of Biotechnology, Thapar Institute of Engineering and Technology, Patiala, Punjab, India

K. Younis
Department of Bioengineering, Integral University, Lucknow, Uttar Pradesh, India

T. Yasin
Institute of Home Science, University of Kashmir, Srinagar, Jammu & Kashmir, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_12

Keywords

Dietary fibre · Bioactive compounds · Functional foods · Phytochemicals

12.1 Introduction

Fruits and vegetables often referred to as 'fresh produce' are important constituents of a healthy diet. These foods supply essential nutrients including vitamins, minerals and dietary fibre which help in maintaining proper physiology. Plant foods, in general, are a source of wide range of bioactive compounds also known as phytochemicals. Many of the phytochemicals possess medicinal properties (Jongen 2002). Some of these phytochemicals possessing medicinal properties are shown in Table 12.1. Fruits and vegetables being the foods of plant origin are rich in these bioactive compounds. The production and consumption of fruits and vegetables have shown gradual increase in the past few decades. This increase is attributed to the healthiness of these foods. Since most of the fruits are consumed in fresh form or after minimal processing, thus allowing the consumers to eat these foods while most of the naturalness is intact.

Functional foods are the processed foods which are supposed to be nutritious and at the same time positively modulate any specific function in the body. The food either helps the body in regulating the physiological responses and/or improves the resistance of body for different diseases (Nicoletti 2012). Functional food carries a

Table 12.1 Phytochemicals with nutraceutical properties

Phytochemical	Phenolic compounds	Nutraceutical properties	Source	Reference
Phenolic compounds	Benzoquinone, phenolic acids, acetophenones, xanthones, flavonoids, lignans, anthraquinones, tannins	Antioxidant	Berries, apples, citrus fruit, cocoa, grapes, onions, olives, tomatoes, broccoli, lettuce, soybeans	Birt et al. (2001)
Terpenoids	Phytosterols, triterpenes, tocotrienols, tocopherols, carotenoids, limonoids	Cholesterol lowering, protective role of phytosterols against colon, prostate and breast cancer	Tomato, citrus fruit, avocado	Moreau et al. (2002), Jones and AbuMweis (2009)
Dietary fibre	Hemicelluloses, cellulose, lignin, oligosaccharides, pectins, gums and waxes	Anti-cancer	Whole fruits and vegetables	Trowell et al. (1985)

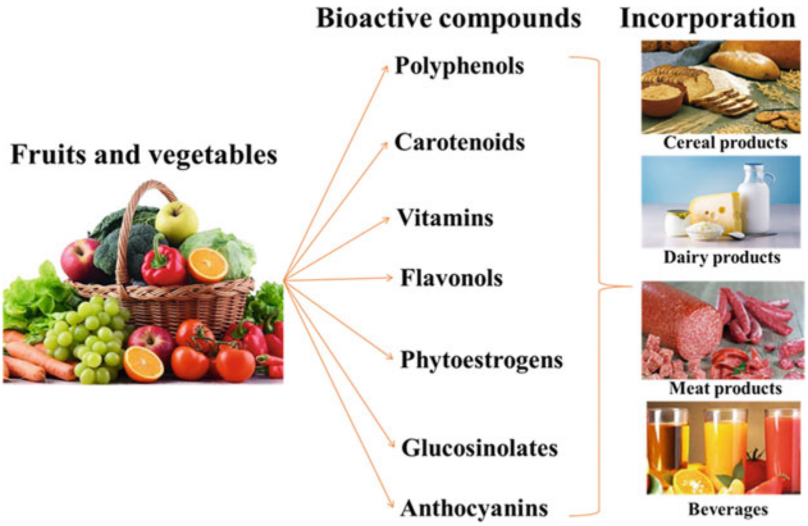


Fig. 12.1 Potential of fruits and vegetables as source of functional foods

functional ingredient which may be a macronutrient or a micronutrient or even a nonnutritive component. These functional ingredients may be derived from plants, animals, or microorganisms. Phytochemicals possessing such properties are appropriate for use in functional foods. A significant population of the world being vegetarian, also makes plant-based functional foods popular. The plant foods include cereal-based foods and fruit and vegetable-based foods. The demand for fruit and vegetable-based functional foods is showing gradual increase owing to the perceived naturalness of fruits and vegetables (Starling 2005). The important phytochemicals may either be extracted from fruits and vegetables and then incorporated into different foods to induce functional character or fruits and vegetables may be directly added to the formulation (Fig. 12.1).

12.2 Fruits as Source of Functional Foods

There are numerous studies on the development of fruit-based foods possessing potential health benefits (Table 12.2). Many researchers have demonstrated the role of fruit-derived phytochemicals in disease prevention and health promotion. The natural character and glorification of the health benefits of fruits in recent times, in addition to concept of functional foods, have paved the way for the extensive research in the development of fruit-based functional foods.

There are various nutrients and health-enhancing bioactive components found in fruits such as polyphenols, vitamin A, vitamin C, minerals and dietary fibre (Sun-Waterhouse 2011). For instance, the role of proanthocyanidins present in cranberries in treating urinary tract infections has been reported as early as 1920

Table 12.2 Fruit-based functional foods

Food	Source	Functional ingredient/ Health benefit	Reference
Apple	Fruit fibre polyphenol smoothie	Fibre, polyphenol	Sun-Waterhouse et al. (2010a)
	Snack bar	Energy control and digestive health protection	Sun-Waterhouse et al. (2010b)
	UHT milk drink	Protection from oxidative stress	Wegrzyn et al. (2008)
	Functional bread with fruit PPs	Polyphenol	Ravi et al. (2009)
	Extruded snack	Antioxidants and fibre	Reis et al. (2014)
Blueberry, cranberry extracts, raspberries, strawberries, blackberries, blackcurrants, gooseberries, chokeberry, elderberry	Blended berry fruit juices	Flavonoids, vitamins and minerals	Buchter-Weisbrodt (2002)
	Antioxidant functional juices	Flavonoids (anthocyanins, flavonols, hydroxycinnamic acid derivatives, stilbenoids, flavan-3-ols, ellagic acid derivatives) and other phenolic acids	Bermudez-Soto and Tomas-Barberan (2004)
	Naturally coloured breakfast cereals (extruded) in opaque bags	Soluble phenolics and anthocyanins	Camire et al. (2002)
Blackcurrant	Novel blackcurrant juices containing probiotic cultures (*Lactobacillus plantarum* 299v)	Probiotics	Luckow and Delahunty (2004)
Citrus	Fruit juice and skim milk mixtures	Antioxidants	Zulueta et al. 2007
	Fruit juice supplements with probiotic cultures	*Lactobacillus* and *Bifidobacterium* strains	Sheehan et al. (2007)
Peach	Novel restructured fruit alginate mixed gel systems	Fruit-alginate	Mancini and McHugh (2000)
Prune	Plum juice vs. a non-fruit source of fibre, psyllium (Metamucil) and equicaloric, fibre-free clear apple juice (placebo control)	Improve bowel regularity and have the satiety potential as to reduce appetite and excess body weight	Cheskin et al. (2009)

(Avorn et al. 1994). The consumption of cranberries has also been related to protection of oral cavities from bacteria (Leahy et al. 2001). Such studies highlighting the medicinal properties of different fruits have led to gradual increase in the demand of functional ingredients entirely from the fruits. Owing to the fresh and natural character of fruits, functional drinks of fruit origin have already been developed in different countries like Poland, USA, and New Zealand. Many fruits have been used in the development of the functional drinks like cranberry, apple, blackcurrant, acai, acerola, guarana, mango, grapes, cherries, kiwifruits, strawberries, peach, plums, blueberry, and pomegranate (Sun-Waterhouse 2011).

12.3 Vegetables as Source of Functional Foods

Vegetable is any edible part of the plant unlike a fruit, which is a mature floral part. Many fruits are categorized as vegetables depending on the way of their use, such as tomato. Vegetables are abundant source of minerals and dietary fibre; however, they may be rich in bioactive compounds as well. Tomato contains lycopene, a primary carotenoid, which possesses anti-cancer properties. Lycopene has been reported as the most efficient oxygen quencher in biological systems (Di Mascio et al. 1989). It has been observed that the serum levels of lycopene have an inverse relation with the risk of developing cancer in breast, digestive tract, cervix, bladder, skin, and lung (Hasler 1998). Garlic is very well known for the health benefits including anti-cancer, antibiotic, anti-hyper sensitive and cholesterol-lowering properties (Srivastava et al. 1995). Most of these properties are attributed to sulphur-containing compounds formed by the decomposition of allicin. Cruciferous vegetables on the other hand are rich in glucosinolates. Glucosinolates are the glycosides that have been shown to possess anti-cancer properties.

Fruits and vegetables are abundant sources of dietary fibre. Dietary fibre is the component of plant cells which cannot be digested by humans and includes hemicelluloses, cellulose, lignin, oligosaccharides, pectins, gums and waxes (Trowell et al. 1985). The intake of dietary fibre has been related to reduced risk of colon cancer and many other benefits. The consumption becomes more important for the people who generally eat animal foods and refined foods.

12.4 Technology

Developing a new product is a cumbersome and expensive process. Launching any product in the market is a result of research and development activity in addition to detailed market study. Still majority of the food products launched in the market fail miserably. This process becomes even more difficult when it comes to functional foods. Any functional food can be successful only if the message is effectively conveyed to the consumers and the product is according to the consumer preferences. At the end of the day, the chances of a product to be successful are highly dependent on sensory attributes, price, and appeal of health claim to

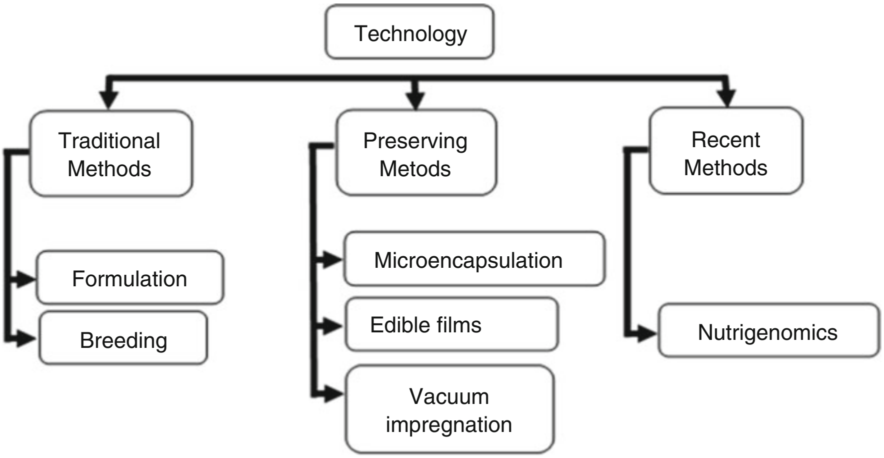


Fig. 12.2 Technology used for the development of functional foods (Betoret et al. 2011)

consumers (Betoret et al. 2011). Betoret et al. (2011) have classified the technologies for developing the functional foods in three groups as (Fig. 12.2) follows:

Traditional food processing technologies: The simplest process of developing a functional food is to blend different functional ingredients in a regular food according to a well-calculated formulation. Fruit and vegetable extracts may be incorporated in different foods to increase their healthiness. Fruits and vegetables may be added in their fresh form or any other modified form which may be whole or only a part. For instance, meat products are enriched with many bioactive compounds including dietary fibre (Jimenez-Colmenero et al. 2010).

The other traditional method is the use of biotechnology in the improvement of crop nutritional quality. The techniques like molecular biology tools have enabled us to develop genetically modified seeds. The produce obtained from such plants are high in nutritional quality. Potato has been fortified with vitamin A (Tanumihardjo et al. 2008) and tomato with vitamin E (de La Garza et al. 2007) through genetic modification.

Techniques preventing deterioration of functional ingredients: The functional ingredients that are an essential component of the functional foods in many instances may be vulnerable to deterioration because of processing, storage, etc. The functional food will lose its functional character if the bioactive compound responsible for the specialty of this food is lost. Different processes may be undertaken to preserve the character of functional ingredient in such foods including microencapsulation, coating the foods with edible material carrying active ingredients and vacuum impregnation (Betoret et al. 2011).

Recent technologies: The most recent technology that may help in the development of functional food is using nutragenomics or nutritional genomics. This approach is based on the compatibility and ability of different individuals to perceive different diets which has been related to the genetic character of individuals. Based on this method, an individual may be provided with a tailored diet plan strictly as per his requirements (Ferguson et al. 2010).

12.5 Prospects

The growing consciousness in consumers regarding their health throughout the world is a driving force for the functional food industry. Markets all around the world are witnessing increase in the launch of functional foods and this trend is expected to remain similar in the near future. Fruits and vegetables being an important source of micronutrients and bioactive compounds remain as the preferred choice for the development of functional foods. Fruits and vegetables also present a wide variety in terms of colour, flavours, and bioactive components, thus providing a potential for the development of huge number of different products. The safety and sensory attributes are the primary requirements of any food product being brought into the market. The success of functional foods, however, will be dependent on the assessment of the delivery of health benefits to consumers. Moreover, the laws governing the manufacture and sale of functional foods are being set up throughout the world while in many countries such laws are already in place. Any manufacturer if planning to bring in a functional food in the market must prove the claim with scientific evidence before the launch of the product. For the development of functional foods, the traditional technologies are expected to continue as usual. The role of modern technologies in the development of such foods is promising, and we will have to wait for assessment of the actual success of these methods.

References

Avorn J, Monane M, Gurwitz JH, Glynn RJ, Choodnovskiy I, Lipsitz LA (1994) Reduction of bacteriuria and pyuria after ingestion of cranberry juice—a reply. JAMA 272:589–590

Bermudez-Soto MJ, Tomas-Barberan FA (2004) Evaluation of commercial red fruit juice concentrates as ingredients for antioxidant functional juices. Eur Food Res Technol 219:33–141

Betoret E, Betoret N, Vidal D, Fito P (2011) Functional foods development: Trends and technologies. Trends Food Sci Technol 22(9):498–508. https://doi.org/10.1016/j.tifs.2011.05.004

Birt DF, Hendrich S, Wang W (2001) Dietary agents in cancer prevention: flavonoids and isoflavonoids. Pharmacol Ther 90(2–3):157–177

Buchter-Weisbrodt H (2002) Berry juices for health. Fluessiges Obst 69:240–242

Camire ME, Chaovanalikit A, Dougherty MP, Briggs J (2002) Blueberry and grape anthocyanins as breakfast cereal colorants. J Food Sci 67:438–441

Cheskin LJ, Mitola AH, Ridoré M, Kolge S, Hwang K, Clark B (2009) A naturalistic, controlled, crossover trial of plum juice versus psyllium versus control for improving bowel function. Internet J Nutr Wellness 7:1

de La Garza RID, Gregory JF, Hanson AD (2007) Folate biofortification of tomato fruit. Proc Natl Acad Sci U S A 104:4218e4222
Di Mascio P, Kaiser S, Sies H (1989) Lycopene as the most efficient biological carotenoid singlet oxygen quencher. Arch Biochem Biophys 274:532–538
Ferguson LR, Philpott M, Barnett MPG (2010). Nutrigenomics: integrating genomic approaches into nutrition research. Mol Diagn 347e363
Hasler CM (1998) Functional foods: their role in disease prevention and health promotion. Food Technol 52(11):63–70
Jimenez-Colmenero F, Sanchez-Muniz FJ, Olmedilla-Alonso B (2010) Design and development of meat-based functional foods with walnut: technological, nutritional and health impact. Food Chem 123:959e967
Jones PJ, AbuMweis SS (2009) Phytosterols as functional food ingredients: linkages to cardiovascular disease and cancer. Curr Opin Clin Nutr Metab Care 12(2):147–151
Jongen W (ed) (2002) Fruit and vegetable processing: improving quality. Elsevier
Leahy M, Roderick R, Brilliant K (2001) The cranberry—promising health benefits, old and new. Nutr Today 36:254–265
Luckow T, Delahunty C (2004) Which juice is healthier? A consumer study of probiotic non-dairy juice drinks. Food Qual Prefer 15:751–759
Mancini F, McHugh TH (2000) Fruit-alginate interactions in novel restructured products. Nahrung 44:152–157
Moreau RA, Whitaker BD, Hicks KB (2002) Phytosterols, phytostanols, and their conjugates in foods: structural diversity, quantitative analysis, and health-promoting uses. Prog Lipid Res 41 (6):457–500
Nicoletti M (2012) Nutraceuticals and botanicals: overview and perspectives. Int J Food Sci Nutr 63 (Suppl 1):2–6
Ravi A, Perera C, Quek SY, Sun-Waterhouse D (2009) Physico-chemical properties of bread dough fortified with fruit fibers and phenolic antioxidants. In: IFT 2009, June, Anaheim/OC, CA, USA
Reis SF, Rai DK, Abu-Ghannam N (2014) Apple pomace as a potential ingredient for the development of new functional foods. Int J Food Sci Technol 49(7):1743–1750
Sheehan VM, Ross P, Fitzgerald GF (2007) Assessing the acid tolerance and the technological robustness of probiotic cultures for fortification in fruit juices. Innov Food Sci Emerg Technol 8:279–284
Starling S (2005) Fruit dons 'healthy' halo. Funct Foods Nutr 6:–6
Sun-Waterhouse D (2011) The development of fruit-based functional foods targeting the health and wellness market: a review. Int J Food Sci Technol 46(5):899–920
Sun-Waterhouse D, Nair S, Wibisono R et al (2010a) Insights into smoothies with high levels of fibre and polyphenols: factors influencing chemical, rheological and sensory properties. World Acad Sci Eng Technol 65:276–285
Sun-Waterhouse D, Teoh A, Massarotto C, Wibisono R, Wadhwa S (2010b) Comparative analysis of fruit-based functional snack bars. Food Chem 119:1369–1379
Srivastava KC, Bordia A, Verma SK (1995) Garlic (Allium sativum) for disease prevention. S Afr J Sci 91:68–77
Tanumihardjo SA, Bouis H, Hotz C, Meenakshi JV, McClafferty B (2008) Biofortification of staple crops: an emerging strategy to combat hidden hunger. Compr Rev Food Sci Food Saf 7:329e334
Trowell HU, Burkitt DE, Heaton KE (1985) Definitions of dietary fibre and fibre-depleted foods. Dietary fibre, fibre-depleted foods and disease. Academic, New York, pp 21–30
Wegrzyn TF, Farr JM, Hunter DC et al (2008) Stability of antioxidants in an apple polyphenol-milk model system. Food Chem 109:310–318
Zulueta A, Esteve MJ, Frasquet I, Fragola A (2007) Vitamin C, vitamin A, phenolic compounds and total antioxidant capacity of new fruit juice and skim milk mixture beverages marketed in Spain. Food Chem 103:1365–1374

Role of By-products of Fruits and Vegetables in Functional Foods

13

Faizan Ahmad, Sadaf Zaidi, and Saghir Ahmad

Abstract

A large number of by-products of fruits and vegetables such as peel, pomace, and seeds are produced around the world from different sources, especially from food processing industries. Most of the times these by-products go unutilized or are discarded as wastes into landfills. On the other hand, these large volume, low cost, readily available by-products of fruits and vegetables possess many components such as vitamins, minerals, and bioactive compounds such as phenolic acids, flavonoids, terpenes, and terpenoids that are good for human health and also possess various antioxidant, antimicrobial, anticancer, and antifungal activities. Moreover, as a whole or as a compound extracted from these wastes can be used for the development of functional foods. Functional foods are the whole, fortified, enriched, or enhanced foods that have a potentially positive effect on health beyond basic nutrition when consumed as part of varied diet regularly. A familiar example of functional food is oatmeal because it contains soluble fibre that can help lower cholesterol levels. Some foods are modified to have health benefits such as orange juice that has been fortified with calcium for bone health. Nowadays, consumer prefers foods not only to satisfy their hunger but also to get additional pre-health components. They are equally conscious to know the constituents of the food items having the health benefits that help in protecting them from diseases. In recent years, the market for functional foods has seen a tremendous upswing. The main objective of this chapter is to discuss the role of by-products of fruits and vegetables in functional foods as well as their benefits for human health. Further, it also aims to focus on the commercial products available in the market having compounds extracted from by-products of fruits and vegetables.

F. Ahmad (✉) · S. Zaidi · S. Ahmad
Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_13

Keywords

Functional foods · Bioactive compounds · By-products of fruits and vegetables

13.1 Functional Foods: An Introduction

These days people have become very conscious about the foods that they consume. Due to the increasing rate of chronic health conditions such as heart attack, high blood pressure level, diabetes, and high cholesterol people have started to choose their food options wisely (Eyre et al. 2004). This happens because there is a strong relationship exists between the foods that the people consume and their health. The concept of functional foods results from this relationship only. A healthy diet can be achieved by consuming foods that are rich in nutritional values other than having good taste. In other words, almost all foods, to some extent, are functional because they provide good taste, aroma as well as great nutritive value. But functional foods have other additional properties which enhance our health and satisfy our metabolic needs. Hence, any food can be called as functional food if it results in a positive impact on our health, the physical performance of our body, or our state of mind, in addition to the nutritional value that it provides (Cencic and Chingwaru 2010; Rincón-León 2003). The concept of functional food was first introduced in the 1980s in Japan by the *Ministry of Health and Welfare* to combat the increasing health care costs and to improve the health of their nation's population (Hasler 2002). Under this scheme, certain foods were approved by the ministry which documented health benefits. These foods are now recognized as *Foods for Specified Health Use (FOSHU)*. In July 2002, around 300 food items have been granted the status of FOSHU in Japan (Arai et al. 2002; Saito 2007).

13.2 Various Definitions of Functional Foods

Several organizations have proposed different definitions of functional foods according to their respective researches. In the year 1994, the *National Academy of Sciences, Food and Nutrition Board* defined functional foods as "any modified food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains" (Aronson 2017; Hasler 2002). Another definition was given by *The International Life Sciences Institute.* According to them "foods that by virtue of the presence of physiologically active components, provide a health benefit beyond basic nutrition" (Hasler 2002; Prates and Alfaia 2002).

The American Dietetic Association (ADA) in the year 1999 defined functional foods as foods that are "whole, fortified, enriched or enhanced foods and have a potentially beneficial effect on health when consumed as a part of a varied diet on a regular basis, at effective levels" (Hasler and Brown 2009). Further, the ADA classified functional foods into four categories: conventional foods, modified foods, medical foods, and food for special dietary use.

It is important to note here that "nutraceuticals" is a term which is used interchangeably with functional foods. It was coined in 1991 by the Foundation for Innovation in Medicine to denote any bioactive component that gives health benefits (Das et al. 2012).

In the year 2006, *Food Safety and Standards Authority of India (FSSAI)* defined functional food in the Indian context as food which influences specific functions in the body that may provide added health benefits or remedy from some diseased condition following the addition/concentration of a beneficial ingredient, or removal/substitution of an ineffective or harmful ingredient (Sheikh and Mohan 2015). Foods might inherently possess these supposedly beneficial qualities, or they may be functionally/modified and/or genetically altered.

13.2.1 Status of Functional Foods in the Indian Market

The demand of functional foods has increased worldwide in recent years. The same trend has been observed in the Indian market too. Along with the increasing demand and market of functional foods in India, the nutraceutical market also gained tremendous growth in the last 10 years. It was estimated that out of the $117 billion global market of nutraceuticals in 2008, India's share was only 0.9% (Keservani et al. 2014). With the increasing penetration of preventative health care products in the Indian market, growing health awareness, higher disposable income, and other factors, the Indian nutraceutical industry has shown a promising compound annual growth rate (CAGR) of 18% in the last 3 years (Keservani et al. 2014). The current scenario indicates that the present value of Indian nutraceutical market is of US$4 billion, but it is expected that it may grow further up to 21% by 2022 and reach about the US$10 billion (Bhupathiraju et al. 2019) (Economic Times, July 14, 2017). The global nutraceutical market is expected to reach $241.1 billion by 2019. One of the recent reports published on 15th April 2019 indicates that the global functional foods market was valued at US$153,600 million in 2018 and is expected to reach US$260,400 million by the end of 2025, thus attaining a CAGR of 6.8% during 2019–2025 (https://www.reuters.com/brandfeatures/venture-capital/article?id=100055). The nutritional benefits of functional foods have endeared them to the Indian markets. The functional food market in India deals with products like fruits, vegetables, fortified juices, fibre-rich foods, cereals, energy drinks, and fresh dairy products, which provide desired health benefits and physiological changes (Kearney 2010). The main ingredients of these products are omega fatty acids, tocopherols, phytoestrogens, fortified foods, prebiotics, probiotics, xylitol, soy, gluten, and whey proteins. Other than being popular for the various health benefits that they possess functional foods are equally famous for having economic benefits too. It has been observed that they have a much higher profitability margin as compared to conventional foods. Thus, they contribute to accelerating economic growth also. Factors such as urbanization, increasing population, demographics, and the desire of Indian consumers to stay fit and maintain a healthy life style are some important forces that are driving the functional foods market (de Jong et al. 2003;

Lajolo 2002). Although this market is in its infancy and needs further development, but the demand for functional foods would continue to increase due to its various benefits. According to some recent reports, the Indian government plans to invest around $21.5 billion in this market in the coming next 5 years. Though at present, there are only a few functional foods suppliers in the country.

13.2.2 Classification of Functional Foods

From the past several years, researchers are not only interested to find out the basic and essential role of food as the source of nutrients, vitamins, minerals, and energy, but they are equally interested to explore the action of food components on human health. Nowadays, consumers are keen to know the potential role of food components in their well-being and life prolongation. Therefore, several industries have developed a wide range of functional foods all over the world to provide various health benefits beyond their nutritional value. It is too difficult to classify the functional foods in one group or in one category; therefore, several studies have classified the functional foods in different categories on the basis of their potential medicinal benefits, properties of their ingredients, advantages, and their role in reducing several chronic diseases (Abdel-Salam 2010; Cencic and Chingwaru 2010). Homayouni et al. (2012), reported the classification of functional foods in ten categories such as prebiotic, probiotic, symbiotic, sugar-reduced, fat-reduced, and salt-reduced foods, as well as the foods, enriched with antioxidants, like anthocyanins, phytosterols, isoflavones, as shown in Fig. 13.1. Probiotic functional foods have exerted a positive effect on the overall health of human beings. Probiotic

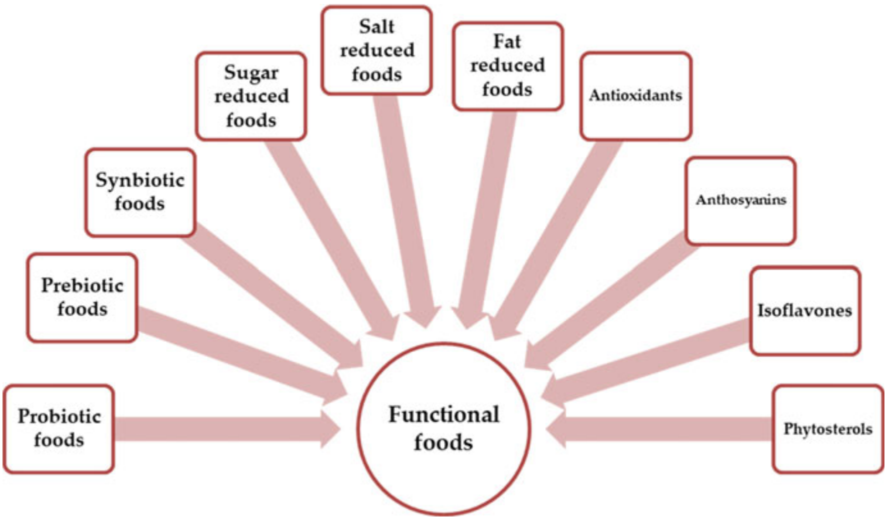


Fig. 13.1 Classification of functional foods

foods can be further divided into two types, such as probiotic dairy foods and non-dairy probiotic foods. Rincón-León (2003), classified the functional foods in 11 groups such as dietary fibre, peptides, proteins, vitamins, minerals, amino acids, polyunsaturated fatty acids, sugar alcohols, oligosaccharides, cholines, glycosides, lactic acid bacteria, and others (phytochemicals and antioxidants). Further, Chen et al. (2011), also mentioned the classification of cholesterol lowering functional foods and nutraceuticals on the basis of seven types of competitors, inhibitors, and activators namely, intestinal acyl-CoA:cholesterol acyltransferase 2 (ACAT2) inhibitors, bile acid reabsorption inhibitors, and plasma cholesteryl ester transporting protein (CETP) inhibitors, cholesterol-7a-hydroxylase (CYP7A1) activators, LDL receptor up-regulators, 3-hydroxy-3-methylglutaryl (HMG-CoA) reductase inhibitors, intestinal Niemann-Pick C1 Like 1 (NPC1L1) competitors. Some of the functional foods with their bioactive ingredients and potential benefits are summarized in Table 13.1.

13.2.3 Classification of Biologically Active Components Present in Functional Foods

Functional foods provide additional or physiological benefits other than providing the nutritional benefits to reduce the risk of chronic/deep-rooted diseases by adding new ingredients or more of existing ingredients. Ingredients providing physiological or beneficial effects in functional foods are called biologically active components (Dwyer et al. 2007; Grusak and DellaPenna 1999; Miguel 2010). Biologically active components include:

- Polysaccharides
- Functional sweetening agents
- Functional grease
- Free radical scavengers
- Vitamins (A, E, and C)
- Minor active elements
- Peptides and proteins
- Lactic acid bacteria
- Other active elements (polyphenols and flavonoids)

13.2.4 Bioactive Compounds in Plants and Their Classification

Bioactive compounds are functional ingredients that occur in nature. These naturally occurring compounds are widely present in fruits, vegetables, and its by-products. Bioactive compounds or phytochemicals can be categorized based on various criteria, for example, according to Liu (2013), they can be grouped as nutrients, minerals, dietary fibres, and vitamins. Phytochemicals can also be classified based upon their chemical nature such as amines, phenols, organic acids, terpenes,

Table 13.1 Bioactive ingredients of food, their sources, and potential benefits

Functional foods	Bioactive ingredients	Potential benefits	References
Buckwheat	Protein and dietary fibre	Lowering the risk of cardiovascular diseases (CVDs) improves bone health	Li et al. (2018)
Cranberry juice	Proanthocyanidins	Reduces urinary tract infections	Asma et al. (2018), Howell (2002)
Dark green leafy vegetables	Lutein	Helps in reducing the risk of blindness in aged people	Pratt (1999), Seddon et al. (1994)
Eggs	Omega-3 content	*Helps in the reduction of coronary diseases*	Bowen et al. (2016), Yalcin and Unal (2010)
Fermented dairy products	Probiotic lactobacillus and bifid bacteria	*Helps in lowering the cholesterol level,* improves gastrointestinal complaints	de Vrese et al. (2011), Kawase et al. (2000)
Fruits	Anthocyanidins	Neutralizes free radicals, reduces risk of cancer	Wang and Stoner (2008)
Garlic	Organo sulphur compounds, S-propyl cystein	Helps in reducing the cholesterol levels	Aslani et al. (2016)
Grape seed	flavonols, catechins, anthocyanins, and proanthocyanidins	Lowering cholesterol level	Duchnowicz et al. (2012), Xia et al. (2010)
Meats	Conjugated linoleic acid	Helps in the prevention of breast cancer, improves body composition	den Hartigh (2019)
Psyllium	Soluble fibre	Lowers cholesterol levels	Brown et al. (1999)
Chewing gums and candies (sugarless)	Xylitol	Helps in reducing the dental cavity	Nayak et al. (2014)
Soybean	Proteins, and peptides	*Helps in lowering* plasma *cholesterol, reduces* the risk of heart disease	(Krul and Gillies 2009)
Yogurt and other dairy products	*Lactobacillus* and *Bifidobacterium*	Improves gut health	Redondo-Useros et al. (2019); Rezac et al. (2018)

polysaccharides, and organosulphurs. These compounds are well known for their antimicrobial, antioxidant, anticancer, and anti-inflammatory activities. The plant products having different activities are widely used as medicinal agents for treating various diseases (Tungmunnithum et al. 2018). Further, they can also be used in modern medicines and other industries such as in agriculture, nanotechnology, food and flavouring industry, and cosmetics industry. Examples of modern medicine of plant origin include aspirin, digoxin, quinine, and morphine (Vickers et al. 2001). As

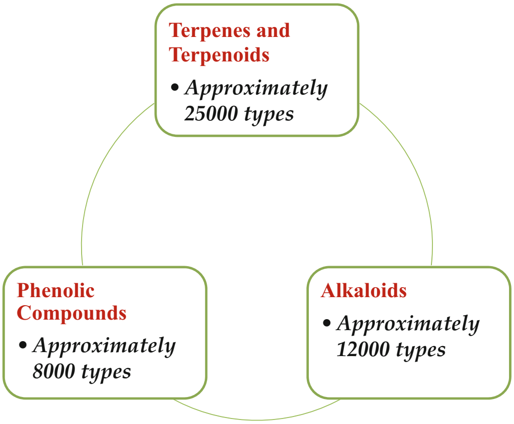


Fig. 13.2 Major classes of plant's bioactive compounds

far as fruits, vegetables, and their by-products are concerned; a large number of bioactive compounds are generally present in them such as polyphenols, flavonoids, glucosinolates, polysaccharides, lignans, carotenoids, kaempferol, taurine, dithiolthiones, ferulic acid, quercetin phytosterols, choline, phytoestrogens, and anthocyanins. For example, banana peel contains flavonols (rutin), hydroxycinnamic acid (ferulic acid), and catecholamines (dopamine) (Al-Dhabi et al. 2015; Passo Tsamo et al. 2015b; Xu et al. 2014). The plant's bioactive compounds are mainly grouped into three main categories as shown in Fig. 13.2 (Azmir et al. 2013).

Fruits, vegetables, and their by-products are rich in a number of bioactive compounds. The type and composition of these active compounds vary with the type of fruits and vegetables. For example, the apple peel is a rich source of cyanidin-3-galactoside, (−)-epicatechin and quercetin glycosides, chlorogenic acid, (+)-catechin, (−)-epicatechin, phloridzin, and rutin (Łata et al. 2009). These phenolic compounds help in preventing diseases such as asthma, cancer, cardiovascular diseases, and diabetes. These compounds are especially known for their antioxidant activity. Apple pomace is also an abundant residue (about one-fourth of the total processed fruits) acquired after the extraction of apple juice (Bhushan et al. 2008). It is also a good source of polyphenols (Schieber et al. 2003) such as phloretin glycosides, quercetin glycosides, catechins, hydroxycinnamates, and procyanidins (Schieber et al. 2001a; Yeap Foo and Lu 1999). Other than the peel of apple the peel of banana also contains high levels of dietary fibre and phenolic compounds like rutin, ferulic acid, tannis, dopamine, procyanidin B2, and gallocatechin, and they can be used for various purposes (Al-Dhabi et al. 2015; Passo Tsamo et al. 2015a; Pereira and Maraschin 2015; Rebello et al. 2014; Vu et al. 2018). Among the peels from various fruits such as banana, papaya, melon, pineapple, and watermelon, the banana peel has the second highest content of phenolic compounds (Morais et al. 2015). The quantity of phenolic compounds present in the banana peel ranges between 4.95 and 47 mg GAE/g DM, which is 1.5–3 folds higher than its flesh, as reported by González-Montelongo et al. (2010) and Hernández-Carranza et al. (2016).

Like apple and banana peel, mango peel also contains carotenoids, dietary fibres, and polyphenols like quercetin, syringic acid, mangiferin pentoxide, and ellagic acid (Ajila et al. 2007). Lakshminarayana et al. (1970) reported that at all stages during the development of mango fruit, the number of total phenols was found to be greater in the peel than in the flesh. It has also been reported that approximately, 4000 mg GAE/kg (dry matter) of total polyphenol is present in mango peels. While raw peels of mango contain lesser total polyphenols than ripe peels (Ajila et al. 2007; Berardini et al. 2005).

Just like other fruits, the by-products of grapes also contain a number of nutrients and bioactive compounds such as the well-known polyphenols of plant origin like phenolic acids, flavonoids, stilbenes, and tannins. One of the categories of the compounds predominantly found in grapes are polyphenols with well-known antioxidant activity (de Sales et al. 2018). The pomace that contains seeds are also rich in non-anthocyanin phenolic compounds like gallic acid, catechin, epicatechin, and β-type (epi) catechin dimer. Gallic acid especially is present in large amount in the seeds of grapes. While the skin of the grapes are reported to have high levels of anthocyanins such as malvidin-rutinoside, petunidin-rutinoside, malvidin-hexoside, and delphinidin-rutinoside. These compounds in the pomace also exhibit interesting bioactivities such as antibacterial and antioxidant activities. The by-products from the grapes are also used in the food industry, as natural antioxidants, and as colour additives (Peixoto et al. 2018). Therefore, instead of disposing of these by-products as waste, they can be used in various industries which will also help to reduce the environmental burden. Since these waste products contain mainly nutrients and bioactive compounds, they are most suitable for their use in cosmetics, pharmaceutical, and food industries. Table 13.2 indicates the bioactive compounds present in some highly consumed fruits and vegetables and their by-products.

13.3 Important Aspects in the Development of Functional Foods with Bioactive Ingredients

As mentioned in the above section, the fruits, vegetables, and their by-products are a rich source of bioactive ingredients. Nowadays, people are more conscious about good health, and they are equally interested to consume such kinds of foods which impart potential benefits and helps in reducing various types of diseases. So, the development of functional foods containing bioactive ingredients has achieved more prominence. The developed functional foods with bioactive ingredients have many activities such as antimicrobial, antioxidant, and anticancer and also they are equally helpful in the interception of cardiovascular diseases (Galanakis 2017; Mahfoudhi et al. 2016). But the efficacy of the functional foods in the interception of diseases

Table 13.2 Bioactive compounds present in fruits and vegetables by-products

Fruits and vegetables by-products	Major classes of compounds	Potential benefits	Activity	Reference
Apple peel	Phenolic compounds such as phloridzin and rutin	Helps in the treatment of Alzheimer's disease	Antioxidant and antimicrobial	Awad et al. (2000), Łata et al. (2009), Al-Dhabi et al. (2015)
Apple pomace	Polyphenols such as catechins, hydroxycinnamates, phloretin glycosides, quercetin, and glycosides	Helps in reducing the risk of obesity, diabetes, and cancer	Antioxidant	Xu et al. (2016), Awad et al. (2000), Schieber et al. (2001b, 2003), Rana and Bhushan (2016)
Apple seeds	Polyphenols such as dihydrochalcones, quercetin, and hydroxycinnamic acids	Used as antioxidants in food or cosmetics	Antioxidant and anti-diabetic	Xu et al. (2016), Ehrenkranz et al. (2005)
Banana peel	Flavonols	Used as natural antioxidant for food supplements	Antioxidant, antimicrobial, and antifungal	Passo Tsamo et al. (2015a), Al-Dhabi et al. (2015)
	Hydroxycinnamic acids	Acts as a preserving agent/skin protection agent	Antimicrobial, anti-inflammmatory, and anticancer	Passo Tsamo et al. (2015a), (Ou and Kwok 2004), Srinivasan et al. (2007)
	Catecholamines	Preservative agent/ Parkinson's medicine	Antioxidant and neurotransmitter	González-Montelongo et al. (2010), Oh et al. (2018), Pereira and Maraschin (2015)
Grape peel and seed	*Flavonols*	Used as a dietary *antioxidant* supplement	Antioxidant	Gomes et al. (2019), Yilmaz and Toledo (2004)
	Hydroxybenzoic acids		Antioxidant	
Broccoli (floret)	Glucosinolate	Helps in the treatment of cancer	Antioxidant and anti-carcinogenic activity	Hwang and Lim (2015), Liu et al. 2018)
Broccoli (leaf)	Glucosinolate	Used as a food preservation and colouring agent	Antioxidant and anti-carcinogenic	Jaiswal and Abu-Ghannam (2016); Liu et al. (2018); Prakash and Gupta (2012)

(continued)

Table 13.2 (continued)

Fruits and vegetables by-products	Major classes of compounds	Potential benefits	Activity	Reference
Tomato peel	Carotenoids	Helps in the treatment of breast cancer and prostate cancer	Antioxidant and anticancer	Agarwal and Rao (2000); Reboul et al. (2005)
Carrot peel and pulp	Carotenoids	Helps in the prevention or treatment of Alzheimer's disease, decreased risk of cataract formation, helps in the inhibition of cancer	Antioxidant, antimutagenic, and antitumor	Sharma et al. (2012)

depends on the bioavailability, bioactivity, and stability of active ingredients (Fernandes et al. 2019). In this context, the main challenge is to keep the active components of functional foods in the gastrointestinal tract for a long duration. But it has been observed that a small amount of molecules remain available in gastrointestinal tract after oral administration due to low permeability, less solubility, and due to their less residence time of molecules in the small intestine (Vertzoni et al. 2019; Vieira da Silva et al. 2016). So, a lot of research is needed in this area. Various commercial and non-commercial studies have been conducted in the past several years for the incorporation of bioactive ingredients obtained from plant products into the functional foods such as many researchers have utilized dietary fibre obtained from apple, kinnow, and grapes pomace to enhance the quality and shelf life of bakery and meat products (Lakshminarayan 2011; Mildner-Szkudlarz et al. 2013; Rafeh et al. 2013). Some of them are reported below.

For the development of new, effective, and inventive functional food products, some of the preliminary analysis are required such as the identification and isolation of bioactive ingredients, the analysis of absorption and bioavailability of the added ingredients, the selection of suitable dosage and delivery systems to incorporate bioactive ingredient into the foods, testing the safety of bioactive ingredients added into the foods, studies on product storage stability, and investigation on interaction between active ingredients and other components of food (Recharla et al. 2017).

Dietary fibres also play an important role in functional foods. Dietary fibres are those carbohydrates found in plant and plant products that cannot be digested or absorbed by enzymes of our body. They include cellulose and non-cellulosic polysaccharides such as gums, hemicelluloses, and a non-carbohydrate component lignin (Dhingra et al. 2012). It is widely found in edible plant foods such as fruits, vegetables, nuts, and cereals. The consumption of foods having a large amount of dietary fibre decreases the incidence of several diseases such as they reduce the risk of cardiovascular disorder by decreasing the cholesterol and triglyceride level (Brown et al. 1999). The ingestion of such kind of foods has a positive effect on human health. It is recommended that healthy adults should take 20–35 g of dietary fibre each day (Dhingra et al. 2012; Slavin et al. 2009). Nowadays, dietary fibres are widely used in the development of several functional foods, such as in bakery, oats-based products, beverages, and meat products. Consumption of dietary fibres as naturally occurring form or added as dietary supplement in foods helps in solving many gastrointestinal problems. Their functions include stool bulking, laxation, fermentation, and gut health, hypocholestermic and triglyceridemic actions, as well as postprandial action reduction of glucose and insulin levels (Williams et al. 2017). It is estimated that intake of approximately 30 g of dietary fibre per day reduces the death rate due to coronary diseases by 15–30% (McRae 2017; Riccioni et al. 2012). Therefore, intake of dietary fibre as naturally occurring form or added as a supplement in functional foods reduces the incidence of cardiovascular diseases.

Mildner-Szkudlarz et al. (2013) developed a biscuit as a functional food using grape by-products as an alternative source of dietary fibre and phenol. On the basis of sensory analysis, they found that up to the level of 10% of white grape pomace could be incorporated into the biscuits in order to obtain adequate product (sensorially acceptable). They also confirmed that 10% incorporation of white grape pomace enhance the quality of biscuits in terms of dietary fibre and phenolic compounds. They equally estimated that at this condition on the basis of dry matter biscuits had a total dietary fibre content of 64.86 g per kg and phenolic compound of 30.51 mg per 100 g.

Sharoba et al. (2013) developed a dietary fibre-rich cake for overweight and diabetes patient using a dietary fibre-rich powder obtained from carrot pomace, green pea peels, orange waste, and potato peels. Cakes were prepared from blends of wheat flour (72%) with 5, 10, 15, and 20% fruits and vegetables by-products. They found that the cakes prepared from 20% of by-products of carrot pomace, green pea peels, orange waste, and potato peels had a higher ratio of dietary fibres. On the basis of sensory evaluation, they found that all high fibre-added cake samples were significantly lower in all sensory characteristics than control sample, except samples prepared with 5 and 10% of carrot pomace and orange waste. The results of their study indicated that carrot pomace, green pea peels, orange waste, and potato peels can serve as a great and healthy source of dietary fibres, and they can be incorporated into the formation of cake in order to obtain a suitable, healthy, and sensory acceptable product.

García-Pérez et al. (2005) developed a yogurt with the incorporation of different level of orange fibre. They found that yogurt containing 1% orange fibre showed lower level of syneresis and reflect more red and yellow colour than the control yogurt and yogurt containing 0.6 and 0.8% orange fibre. Further, Sanz et al. (2008) also reported that the addition of fibre obtained from asparagus shoots increased yogurt consistency and imparted a yellowish-greenish colour to the yogurt.

Aportela-Palacios et al. (2005) prepared a fortified yogurt by adding additional fibre and calcium. Three levels of wheat bran were used as a source of dietary fibre. They found that in comparison with a plain yogurt, the presence of fibre and calcium increases the consistency, decreases the syneresis, and increases the pH of the yogurt.

Marsanasco et al. (2015) developed fortified chocolate milk as a functional food with vitamins E and C, omega-6, and omega-3 by using liposomes. They observed that the liposomes showed significant stability of all the parameters. Further, the results of their study prove that the liposomes have a protective effect on thermolabile fatty acids. On the basis of sensory analysis, they also confirmed that the addition of liposomes did not affect the overall acceptability of milk.

Kaderides et al. (2015) improved the quality and shelf life of hazelnut paste by incorporating the extract of pomegranate peel through a new idea of encapsulation to evaluate the stabilizing efficacy of the pomegranate peel extract against oxidative deterioration. They found that the encapsulation of phenolic extract into the hazelnut increases the shelf life of paste effectively.

As far as the meat products are concerned, several studies have been conducted in the past several years in order to increase the quality, fibre content, and shelf life of the meat products. Prasad et al. (2010) incorporated the oat flour in chicken kofta in order to increase its shelf life and quality. They found that the oat flour maintains the quality of chicken kofta up to 15 days of storage as compared to the control sample in terms of microbial growth. Further, they have also observed that the oat flour behaved as a fat replacer and was a good source of antioxidants. Due to the presence of high concentration of polyphenols, the oat flour exhibited antioxidant activity to a greater extent (Emmons et al. 1999).

In a similar study, Modi et al. (2004) incorporated roasted flour in the meat burgers. They observed that the roasted flour increased the shelf life of burger by decreasing the TBA number of the treated samples. Further, they found that the burger was safe to consume up to 4 months of storage at 18 °C and it also reduced the microbial growth. In another study, Modi et al. (2009) observed that the incorporation of oat flour in fried mutton kofta decreased the pH of kofta during storage period of 1.5 months. This means that the incorporation of oat flour increases the shelf of kofta as compared to the kofta without oat flour. It has also been observed that the incorporation of oat flour in meat products not only enhances the quality and shelf life of the product, but it also effects or alters the composition of meat products. Serdaroglu (2006) observed that the incorporation of oat flour in raw and cooked beef patties in low percentage did not affect the fat, protein, and ash content of the patties but if the percentage is increased it decreases the moisture content of the beef patties. Further, Dzudie et al. (2002) and NAVEENA et al. (2006) reported that the incorporation of bean flour and ragi millet flour in beef and chicken patties decreased the protein content of patties.

13.4 Commercial Products Available in the Market

In order to fulfil the requirement and increasing demand of the functional foods and health conscious consumers, various nutraceutical and food industries have developed some functional, specialized foods and food supplements, which meet the consumers demand for a healthy life style, and provide additional health benefits. This has led to the new concept like super food and functional foods. The consumption of these functional foods is not only deliberated to satisfy the hunger of consumers but equally they are also helpful in the prevention of various chronic and non-chronic diseases. These foods also enhance the overall health of their consumers. Some of the commercial products available in the market containing probiotics and bioactive ingredients from fruits and vegetables for improving the health of human beings are shown in Fig. 13.3.

Fig. 13.3 Web grab of some commercial products available in the market

13.5 Conclusion

The chapter discusses about the bioactive compounds present in the by-products of fruits and vegetables that can be obtained from the wastes generated by the consumption of fruits and vegetables in industries and households. Further, this chapter also shows the role of bioactive compounds in the development of functional foods such as in the bakery and meat products. On the basis of the discussion on functional foods and the results of various studies mentioned in the chapter, it has been concluded that these days the consumption of functional foods containing bioactive compounds is one of the best options to improve or maintain a good health in order to fight against various diseases and to reduce disease risk. The bioactive compounds exhibit various biological and medicinal activities such as anticancer, antioxidant, and antimicrobial, so the functional foods containing these compounds also exhibit such activities, and they are equally helpful in reducing various cardiovascular diseases such as heart attack and cancer. Other than the bioactive compounds, the waste of fruits and vegetables are also a good source of dietary fibre. The incorporation of dietary fibre in the bakery and meat products helps to increase the food bulks as well as it also helps to increase the quality and shelf life of the products. Consumption of such foods consequently helps in reducing the various stomach-related diseases such as constipation. Despite the fact that the by-products of fruits and vegetables containing a large number of valuable bioactive compounds are being still disposed off as waste. This might be due to the lack of effective methods to efficiently obtain these compounds from there wastes. A large number of researchers are working around the globe in order to find out the best possible and effective method for the extraction and incorporation of compounds into the functional foods. For example, several commercial products are available in the market in the form of dietary supplements, fibre-rich and fortified cookies, in the form of probiotics dairy products as well as in the form of antioxidants infusion. But still a lot of work has to be done in order to find out the best possible utilization of these by-products and compounds extracted from them.

References

Abdel-Salam A (2010) Functional foods: hopefulness to good health. Am J Food Technol 5:86–99. https://doi.org/10.3923/ajft.2010.86.99

Agarwal S, Rao AV (2000) Tomato lycopene and its role in human health and chronic diseases. CMAJ 163:739–744

Ajila CM, Bhat SG, Rao U (2007) Valuable components of raw and ripe peels from two Indian mango varieties. Food Chem 102:1006–1011. https://doi.org/10.1016/j.foodchem.2006.06.036

Al-Dhabi NA, Arasu MV, Park CH, Park SU (2015) An up-to-date review of rutin and its biological and pharmacological activities. EXCLI J 14:59–63. https://doi.org/10.17179/excli2014-663

Aportela-Palacios A, Sosa-Morales ME, Vélez-Ruiz J (2005) Rheological and physicochemical behavior of fortified yogurt, with fiber and calcium. J Text Stud 36:333–349. https://doi.org/10.1111/j.1745-4603.2005.00020.x

Arai S et al (2002) Recent trends in functional food science and the industry in Japan. Biosci Biotechnol Biochem 66:2017–2029. https://doi.org/10.1271/bbb.66.2017

Aronson JK (2017) Defining 'nutraceuticals': neither nutritious nor pharmaceutical. Br J Clin Pharmacol 83:8–19. https://doi.org/10.1111/bcp.12935
Aslani N, Entezari MH, Askari G, Maghsoudi Z, Maracy MR (2016) Effect of garlic and lemon juice mixture on lipid profile and some cardiovascular risk factors in people 30–60 years old with moderate hyperlipidaemia: a randomized clinical trial. Int J Prev Med 7:95. https://doi.org/10.4103/2008-7802.187248
Asma B, Vicky L, Stephanie D, Yves D, Amy H, Sylvie D (2018) Standardised high dose versus low dose cranberry Proanthocyanidin extracts for the prevention of recurrent urinary tract infection in healthy women [PACCANN]: a double blind randomised controlled trial protocol. BMC Urol 18:29. https://doi.org/10.1186/s12894-018-0342-7
Awad MA, de Jager A, van Westing LM (2000) Flavonoid and chlorogenic acid levels in apple fruit: characterisation of variation. Sci Hortic 83:249–263. https://doi.org/10.1016/S0304-4238(99)00124-7
Azmir J et al (2013) Techniques for extraction of bioactive compounds from plant materials: A review. J Food Eng 117:426–436. https://doi.org/10.1016/j.jfoodeng.2013.01.014
Berardini N, Schieber A, Klaiber I, Beifuss U, Carle R, Conrad J (2005) 7-0-Methylcyanidin 3-0-beta-D-galactopyranoside, a novel anthocyanin from mango (Mangifera indica L. cv. 'Tommy Atkins') peels. J Chem Sci 60:801–804
Bhupathiraju K, Krishnaraju AV, Sengupta K, Golakoti T, Akolkar SK, Datla P (2019) Regulations on nutraceuticals, functional foods, and dietary supplements in India. In: Bagchi D (ed) Nutraceutical and functional food regulations in the United States and around the world, 3rd edn. Academic, San Diego, pp 445–464. https://doi.org/10.1016/B978-0-12-816467-9.00029-0
Bhushan S, Kalia K, Sharma M, Singh B, Ahuja PS (2008) Processing of apple pomace for bioactive molecules. Crit Rev Biotechnol 28:285–296. https://doi.org/10.1080/07388550802368895
Bowen KJ, Harris WS, Kris-Etherton PM (2016) Omega-3 fatty acids and cardiovascular disease: are there benefits? Curr Treat Options Cardiovasc Med 18:69. https://doi.org/10.1007/s11936-016-0487-1
Brown L, Rosner B, Willett WW, Sacks FM (1999) Cholesterol-lowering effects of dietary fiber: a meta-analysis. Am J Clin Nutr 69:30–42. https://doi.org/10.1093/ajcn/69.1.30
Cencic A, Chingwaru W (2010) The role of functional foods, nutraceuticals, and food supplements in intestinal health. Nutrients 2:611–625. https://doi.org/10.3390/nu2060611
Chen Z-Y, Ma KY, Liang Y, Peng C, Zuo Y (2011) Role and classification of cholesterol-lowering functional foods. J Funct Foods 3:61–69. https://doi.org/10.1016/j.jff.2011.02.003
Das L, Bhaumik E, Raychaudhuri U, Chakraborty R (2012) Role of nutraceuticals in human health. J Food Sci Technol 49:173–183. https://doi.org/10.1007/s13197-011-0269-4
de Vrese M, Kristen H, Rautenberg P, Laue C, Schrezenmeir J (2011) Probiotic lactobacilli and bifidobacteria in a fermented milk product with added fruit preparation reduce antibiotic associated diarrhea and Helicobacter pylori activity. J Dairy Res 78:396–403. https://doi.org/10.1017/s002202991100063x
Dhingra D, Michael M, Rajput H, Patil RT (2012) Dietary fibre in foods: a review. J Food Sci Technol 49:255–266. https://doi.org/10.1007/s13197-011-0365-5
Duchnowicz P, Broncel M, Podsędek A, Koter-Michalak M (2012) Hypolipidemic and antioxidant effects of hydroxycinnamic acids, quercetin, and cyanidin 3-glucoside in hypercholesterolemic erythrocytes (in vitro study). Eur J Nutr 51:435–443. https://doi.org/10.1007/s00394-011-0227-y
Dwyer J et al (2007) Measuring vitamins and minerals in dietary supplements for nutrition studies in the USA. Anal Bioanal Chem 389:37–46. https://doi.org/10.1007/s00216-007-1456-z
Dzudie T, Scher J, Hardy J (2002) Common bean flour as an extender in beef sausages. J Food Eng 52:143–147. https://doi.org/10.1016/S0260-8774(01)00096-6
Ehrenkranz JR, Lewis NG, Kahn CR, Roth J (2005) Phlorizin: a review. Diabetes Metab Res Rev. 21(1):31–38

Emmons CL, Peterson DM, Paul GL (1999) Antioxidant capacity of oat (Avena sativa L.) extracts. 2. In vitro antioxidant activity and contents of phenolic and tocol antioxidants. J Agric Food Chem 47:4894–4898. https://doi.org/10.1021/jf990530i

Eyre H, Kahn R, Robertson RM (2004) Preventing cancer, cardiovascular disease, and diabetes a common agenda for the American Cancer Society, the American Diabetes Association, and the American Heart Association. Diab Care 27:1812–1824. https://doi.org/10.2337/diacare.27.7.1812%

Fernandes SS, Coelho MS, Salas-Mellado MDLM (2019) Bioactive compounds as ingredients of functional foods: polyphenols, carotenoids, peptides from animal and plant sources new. In: MRS C (ed) Bioactive compounds. Woodhead, Cambridge, pp 129–142. https://doi.org/10.1016/B978-0-12-814774-0.00007-4

Galanakis CM (2017) Introduction (Chapter 1). In: Galanakis CM (ed) Nutraceutical and functional food components. Academic, London, pp 1–14. https://doi.org/10.1016/B978-0-12-805257-0.00001-6

García-Pérez F, Lario Y, Fernández-López J, Sayas E, Pérez-Álvarez J, Sendra E (2005) Effect of orange fiber addition on yogurt color during fermentation and cold storage. Color Res Appl 30:457–463. https://doi.org/10.1002/col.20158

Gomes TM et al (2019) Differential contribution of grape peel, pulp, and seed to bioaccessibility of micronutrients and major polyphenolic compounds of red and white grapes through simulated human digestion. J Funct Foods 52:699–708. https://doi.org/10.1016/j.jff.2018.11.051

González-Montelongo R, Gloria Lobo M, González M (2010) Antioxidant activity in banana peel extracts: testing extraction conditions and related bioactive compounds. Food Chem 119:1030–1039. https://doi.org/10.1016/j.foodchem.2009.08.012

Grusak M, DellaPenna D (1999) Improving the nutrient composition of plants to enhance human nutrition and health. Ann Rev Plant Physiol Plant Mol Biol 50:133–161. https://doi.org/10.1146/annurev.arplant.50.1.133

den Hartigh LJ (2019) Conjugated linoleic acid effects on cancer, obesity, and atherosclerosis: a review of pre-clinical and human trials with current perspectives. Nutrients 11. https://doi.org/10.3390/nu11020370

Hasler CM (2002) Functional foods: benefits, concerns and challenges—a position paper from the American Council on Science and Health. J Nutr 132:3772–3781. https://doi.org/10.1093/jn/132.12.3772%J

Hasler CM, Brown AC (2009) Position of the American Dietetic Association: functional foods. J Am Dietetic Assoc 109:735–746

Hernández-Carranza P, Ávila-Sosa R, Guerrero-Beltrán JA, Navarro-Cruz AR, Corona-Jiménez E, Ochoa-Velasco CE (2016) Optimization of antioxidant compounds extraction from fruit by-products: apple pomace, orange and banana peel. J Food Proc Preserv 40:103–115. https://doi.org/10.1111/jfpp.12588

Homayouni A, Alikhah H, Alizadeh M, Zijah V (2012) Functional dairy probiotic food development: trends, concepts, and products. In: Rigobelo EC (ed) Probiotics. Rijeka (Croatia), InTech. https://doi.org/10.5772/48797

Howell AB (2002) Cranberry proanthocyanidins and the maintenance of urinary tract health. Crit Rev Food Sci Nut 42:273–278. https://doi.org/10.1080/10408390209351915

Hwang JH, Lim SB (2015) Antioxidant and anticancer activities of broccoli by-products from different cultivars and maturity stages at harvest. Prev Nutr Food Sci 20:8–14. https://doi.org/10.3746/pnf.2015.20.1.8

Jaiswal AK, Abu-Ghannam N (2016) Fermentation-assisted extraction of Isothiocyanates from Brassica vegetable using box-Behnken experimental design. Foods (Basel, Switzerland) 5:75. https://doi.org/10.3390/foods5040075

de Jong N, Ocke MC, Branderhorst HA, Friele R (2003) Demographic and lifestyle characteristics of functional food consumers and dietary supplement users. Br J Nutr 89:273–281. https://doi.org/10.1079/bjn2002772

Kaderides K, Goula A, Adamopoulos K (2015) A process for turning pomegranate peels into a valuable food ingredient using ultrasound-assisted extraction and encapsulation. Innov Food Sci Emerg Technol 31:204–215. https://doi.org/10.1016/j.ifset.2015.08.006

Kawase M, Hashimoto H, Hosoda M, Morita H, Hosono A (2000) Effect of administration of fermented milk containing whey protein concentrate to rats and healthy men on serum lipids and blood pressure. J Dairy Sci 83:255–263. https://doi.org/10.3168/jds.S0022-0302(00)74872-7

Kearney J (2010) Food consumption trends and drivers. Philos Trans R Soc Lond B Biol Sci 365:2793–2807. https://doi.org/10.1098/rstb.2010.0149

Keservani R, Sharma AK, Ahmad F, Baig M (2014) Ch 19: Nutraceutical and functional food regulations in India. In: Bagchi D (ed) Nutraceutical and functional food regulations in the United States and around the world, 2nd edn. Academic, Boston, pp 327–342

Krul ES, Gillies PJ (2009) Translating nutrigenomics research into practice: the example of soy protein. In: Castle R (ed) Nutrition and genomics. Academic, San Diego, pp 25–44. https://doi.org/10.1016/B978-0-12-374125-7.00002-3

Lajolo FM (2002) Functional foods: Latin American perspectives the Br J Nutr 88 Suppl 2:S145-S150 doi:https://doi.org/10.1079/bjn2002679

Lakshminarayan S (2011) Apple pomace (by-product of fruit juice industry) as a flour fortification strategy. In: Preedy VR, Watson RR, Patel VB (eds) Flour and breads and their fortification in health and disease prevention. Academic Press, Boston, pp 395–405. https://doi.org/10.1016/B978-0-12-380886-8.10036-4

Lakshminarayana S, Subhadra NV, Subramanyam H (1970) Some aspects of developmental physiology of mango fruit. J Hortic Sci Biotechnol 45:133. https://doi.org/10.1080/00221589.1970.11514339

Łata B, Trampczynska A, Paczesna J (2009) Cultivar variation in apple peel and whole fruit phenolic composition. Sci Hortic 121:176–181. https://doi.org/10.1016/j.scienta.2009.01.038

Li L, Lietz G, Seal C (2018) Buckwheat and CVD risk markers: a systematic review and meta-analysis. Nutrients 10(5):pii: E619. https://doi.org/10.3390/nu10050619

Liu RH (2013) Health-promoting components of fruits and vegetables in the diet. Adv Nutr 4:384s–392s. https://doi.org/10.3945/an.112.003517

Liu M, Zhang L, Ser SL, Cumming JR, Ku KM (2018) Comparative phytonutrient analysis of broccoli by-products: the potentials for broccoli by-product utilizationMolecules.23(4). pii: E900. doi: 10.3390/molecules23040900. doi:https://doi.org/10.3390/molecules23040900

Mahfoudhi N, Ksouri R, Hamdi S (2016) Nanoemulsions as potential delivery systems for bioactive compounds in food systems: preparation, characterization, and applications in food industry. In: Grumezescu AM (ed) Emulsions. Academic, Amsterdam, pp 365–403. https://doi.org/10.1016/B978-0-12-804306-6.00011-8

Marsanasco M, Calabró V, Piotrkowski B, Chiaramoni N, Alonso S (2015) Fortification of chocolate milk with omega-3, omega-6 and vitamins E and C by using liposomes. Eur J Lipid Sci Technol. 118(9):1271–1281. https://doi.org/10.1002/ejlt.201400663

McRae MP (2017) Dietary Fiber is beneficial for the prevention of cardiovascular disease: an umbrella review of meta-analyses. J Chiropr Med 16:289–299. https://doi.org/10.1016/j.jcm.2017.05.005

Miguel M (2010) Antioxidant and anti-inflammatory activities of essential oils: a short review. Molecules 15:9252–9287. https://doi.org/10.3390/molecules15129252

Mildner-Szkudlarz S, Bajerska J, Zawirska-Wojtasiak R, Gorecka D (2013) White grape pomace as a source of dietary fibre and polyphenols and its effect on physical and nutraceutical characteristics of wheat biscuits. J Sci Food Agric 93:389–395. https://doi.org/10.1002/jsfa.5774

Modi VK, Mahendrakar NS, Narasimha Rao D, Sachindra NM (2004) Quality of buffalo meat burger containing legume flours as binders. Meat Sci 66:143–149. https://doi.org/10.1016/s0309-1740(03)00078-0

Modi V, Yashoda KP, Mahendrakar NS (2009) Low-fat mutton kofta prepared by using carrageenan as fat replacer: Quality changes in cooked product during storage. J Food Sci Technol 46:316–319

Morais DR et al (2015) Antioxidant activity, phenolics and UPLC–ESI(−)–MS of extracts from different tropical fruits parts and processed peels. Food Res Int 77:392–399. https://doi.org/10.1016/j.foodres.2015.08.036

Naveena BM, Muthukumar M, Ar S, Babji Y, Murthy TRK (2006) Quality characteristics and storage stability of chicken patties formulated with finger millet flour (Eleusine coracana). J Muscle Foods 17(1):92–104. https://doi.org/10.1111/j.1745-4573.2006.00039.x

Nayak PA, Nayak UA, Khandelwal V (2014) The effect of xylitol on dental caries and oral flora. Clin Cosmet Investig Dent 6:89–94. https://doi.org/10.2147/CCIDE.S55761

Oh Y-S, Kim J-S, Hwang E-J, Lyoo CH (2018) Striatal dopamine uptake and olfactory dysfunction in patients with early Parkinson's disease. Parkinsonism Relat Disord. https://doi.org/10.1016/j.parkreldis.2018.06.022

Ou S, Kwok K-C (2004) Ferulic acid: pharmaceutical functions, preparation and applications in foods. J Sci Food Agric 84:1261–1269. https://doi.org/10.1002/jsfa.1873

Passo Tsamo CV et al (2015a) Effect of boiling on phenolic profiles determined using HPLC/ESI-LTQ-Orbitrap-MS, physico-chemical parameters of six plantain banana cultivars (Musa sp). J Food Comp Analysis 44:158–169. https://doi.org/10.1016/j.jfca.2015.08.012

Passo Tsamo CV et al (2015b) Phenolic profiling in the pulp and peel of nine plantain cultivars (Musa sp.). Food Chem 167:197–204. https://doi.org/10.1016/j.foodchem.2014.06.095

Peixoto CM, Dias MI, Alves MJ, Calhelha RC, Barros L, Pinho SP, Ferreira I (2018) Grape pomace as a source of phenolic compounds and diverse bioactive properties. Food Chem 253:132–138. https://doi.org/10.1016/j.foodchem.2018.01.163

Pereira A, Maraschin M (2015) Banana (Musa spp) from peel to pulp: ethnopharmacology, source of bioactive compounds and its relevance for human health. J Ethnopharmacol 160:149–163. https://doi.org/10.1016/j.jep.2014.11.008

Prakash D, Gupta C (2012) Glucosinolates: the phytochemicals of nutraceutical importance. J Compl Integr Med 9:Article 13. https://doi.org/10.1515/1553-3840.1611

Prasad B, Rashmi MD, Yashoda KP, Modi V (2010) Effect of casein and oat flour on physicochemical and oxidative processes of cooked chicken kofta. J Food Proc Preserv 35:359–368. https://doi.org/10.1111/j.1745-4549.2009.00475.x

Prates J, Alfaia C (2002) Functional foods from animal sources and their physiologically active components. Revue de Méd Vét 153(3):155–160

Pratt S (1999) Dietary prevention of age-related macular degeneration. J Am Optometric Assoc 70:39–47

Rafeh S, Palanisamy G, Giriprasad R, Yatoo M (2013) Fruit based natural antioxidants in meat and meat products: a review. Crit Rev Food Sci Nutr 55(11):1503–1513. https://doi.org/10.1080/10408398.2012.701674

Rana S, Bhushan S (2016) Apple phenolics as nutraceuticals: assessment, analysis and application. J Food Sci Technol 53:1727–1738. https://doi.org/10.1007/s13197-015-2093-8

Rebello LPG, Ramos AM, Pertuzatti PB, Barcia MT, Castillo-Muñoz N, Hermosín-Gutiérrez I (2014) Flour of banana (Musa AAA) peel as a source of antioxidant phenolic compounds. Food Res Int 55:397–403. https://doi.org/10.1016/j.foodres.2013.11.039

Reboul E et al (2005) Enrichment of tomato paste with 6% tomato Peel increases lycopene and β-carotene bioavailability in men. J Nutr 135:790–794. https://doi.org/10.1093/jn/135.4.790%

Recharla N, Riaz M, Ko S, Park S (2017) Novel technologies to enhance solubility of food-derived bioactive compounds: a review. J Funct Foods 39:63–73. https://doi.org/10.1016/j.jff.2017.10.001

Redondo-Useros N, Gheorghe A, Diaz-Prieto LE, Villavisencio B, Marcos A, Nova E (2019) Associations of probiotic fermented Milk (PFM) and yogurt consumption with Bifidobacterium and Lactobacillus components of the gut microbiota in healthy adults. Nutrients 11. https://doi.org/10.3390/nu11030651

Rezac S, Kok CR, Heermann M, Hutkins R (2018) Fermented foods as a dietary source of live organisms. Front Microbiol 9:1785. https://doi.org/10.3389/fmicb.2018.01785

Riccioni G, Sblendorio V, Gemello E, Di Bello B, Scotti L, Cusenza S, D'Orazio N (2012) Dietary fibers and cardiometabolic diseases. Int J Mol Sci 13:1524–1540. https://doi.org/10.3390/ijms13021524

Rincón-León F (2003) Functional foods. In: Caballero B (ed) Encyclopedia of food sciences and nutrition, 2nd edn. Academic, Oxford, pp 2827–2832. https://doi.org/10.1016/B0-12-227055-X/01328-6

Saito M (2007) Role of FOSHU (food for specified health uses) for healthier life. Yakugaku Zasshi 127:407–416. https://doi.org/10.1248/yakushi.127.407

de Sales NFF et al (2018) Anthocyanin-rich grape Pomace extract (Vitis vinifera L.) from wine industry affects mitochondrial bioenergetics and glucose metabolism in human Hepatocarcinoma HepG2 cells. Molecules 23(3). pii: E611. https://doi.org/10.3390/molecules23030611

Sanz T, Salvador A, Jiménez A, Fiszman SM (2008) Yogurt enrichment with functional asparagus fibre. Effect of fibre extraction method on rheological properties, colour, and sensory acceptance. Eur Food Res Technol 227:1515–1521. https://doi.org/10.1007/s00217-008-0874-2

Schieber A, Keller P, Carle R (2001a) Determination of phenolic acids and flavonoids of apple and pear by high-performance liquid chromatography. J Chromatograph A 910:265–273

Schieber A, Stintzing FC, Carle R (2001b) By-products of plant food processing as a source of functional compounds — recent developments trends in Food. Sci Technol 12:401–413. https://doi.org/10.1016/S0924-2244(02)00012-2

Schieber A, Hilt P, Streker P, Endreß H-U, Rentschler C, Carle R (2003) A new process for the combined recovery of pectin and phenolic compounds from apple pomace innovative. Food Sci Emerg Technol 4:99–107. https://doi.org/10.1016/S1466-8564(02)00087-5

Seddon JM et al (1994) Dietary carotenoids, vitamins a, C, and E, and advanced age-related macular degeneration. Eye Disease Case-Control Study Group. JAMA 272:1413–1420

Serdaroglu M (2006) The characteristics of beef patties containing different levels of fat and oat flour. Int J Food Sci Technol 41:147–153. https://doi.org/10.1111/j.1365-2621.2005.01041.x

Sharma KD, Karki S, Thakur NS, Attri S (2012) Chemical composition, functional properties and processing of carrot-a review. J Food Sci Technol 49:22–32. https://doi.org/10.1007/s13197-011-0310-7

Sharoba PA, Farrag M, El-Salam A (2013) Utilization of some fruits and vegetables waste as a source of dietary fiber and its effect on the cake making and its quality attributes. J Agroaliment Proc Technol 19:429–444

Sheikh S, Mohan B (2015) Functional food acceptance in India: Socio-demographic and lifestyle determinants. 1st IIMA International Conference on Advances in Healthcare Management Services. IIM, Ahmedabad, Gujarat

Slavin JL, Savarino V, Paredes-Diaz A, Fotopoulos G (2009) A review of the role of soluble fiber in health with specific reference to wheat dextrin. J Int Med Res 37:1–17. https://doi.org/10.1177/147323000903700101

Srinivasan M, Sudheer AR, Menon VP (2007) Ferulic acid: therapeutic potential through its antioxidant property. J Clin Biochem Nutr 40:92–100. https://doi.org/10.3164/jcbn.40.92

Tungmunnithum D, Thongboonyou A, Pholboon A, Yangsabai A (2018) Flavonoids and other phenolic compounds from medicinal plants for pharmaceutical and medical aspects: an overview. Medicines (Basel) 5:93. https://doi.org/10.3390/medicines5030093

Vertzoni M et al (2019) Impact of regional differences along the gastrointestinal tract of healthy adults on oral drug absorption: An UNGAP review. Eur J Pharm Sci 134:153–175. https://doi.org/10.1016/j.ejps.2019.04.013

Vickers A, Zollman C, Lee R (2001) Herbal medicine. West J Med 175:125–128. https://doi.org/10.1136/ewjm.175.2.125

Vieira da Silva B, Barreira JCM, Oliveira MBPP (2016) Natural phytochemicals and probiotics as bioactive ingredients for functional foods: extraction, biochemistry and protected-delivery technologies. Trends Food Sci Technol 50:144–158. https://doi.org/10.1016/j.tifs.2015.12.007

Vu HT, Scarlett CJ, Vuong QV (2018) Phenolic compounds within banana peel and their potential uses: A review. J Funct Foods 40:238–248. https://doi.org/10.1016/j.jff.2017.11.006

Wang LS, Stoner GD (2008) Anthocyanins and their role in cancer prevention. Cancer Lett 269:281–290. https://doi.org/10.1016/j.canlet.2008.05.020

Williams BA, Grant LJ, Gidley MJ, Mikkelsen D (2017) Gut fermentation of dietary fibres: physico-chemistry of plant cell walls and implications for health. Int J Mol Sci 18:2203. https://doi.org/10.3390/ijms18102203

Xia E-Q, Deng G-F, Guo Y-J, Li H-B (2010) Biological activities of polyphenols from grapes. Int J Mol Sci 11:622–646. https://doi.org/10.3390/ijms11020622

Xu PX et al (2014) Rutin improves spatial memory in Alzheimer's disease transgenic mice by reducing Abeta oligomer level and attenuating oxidative stress and neuroinflammation. Behav Brain Res 264:173–180. https://doi.org/10.1016/j.bbr.2014.02.002

Xu Y et al (2016) Variation in phenolic compounds and antioxidant activity in apple seeds of seven cultivars. Saudi J Biol Sci 23:379–388. https://doi.org/10.1016/j.sjbs.2015.04.002

Yalcin H, Unal MK (2010) The enrichment of hen eggs with omega-3 fatty acids. J Med Food 13:610–614. https://doi.org/10.1089/jmf.2008.0024

Yeap Foo L, Lu Y (1999) Isolation and identification of procyanidins in apple pomace. Food Chem 64:511–518. https://doi.org/10.1016/S0308-8146(98)00150-2

Yilmaz Y, Toledo RT (2004) Major flavonoids in grape seeds and skins: antioxidant capacity of catechin, epicatechin, and gallic acid. J Agric Food Chem 52:255–260. https://doi.org/10.1021/jf030117h

Lactic Acid Bacteria (LAB) Fermented Food and Their Therapeutic Importance

14

Irfan Khan and Saghir Ahmad

Abstract

Lactic acid bacteria (LAB) are Gram-positive important health beneficial microorganisms and is continuously being used for decades in food production, preservation, quality improvement (taste, texture, aroma, flavour), and a promising source of potential bioactive molecules to boost the human health. Some species of these lactic acid bacteria are able to survive through the gastro-intestinal tract (GIT). They play an important role in the human intestine and are generally recognized as safe organisms by the US Food and Drug Administration (FDA). The food-grade lactic acid bacteria (LAB) are considered as suitable vehicles for the production and delivery of health promoting or therapeutic, bioactive molecules. The bioactive molecules considered for the benefits of health include the endogenous effector molecules produced by probiotics (mostly by lactobacilli genus). Another category of bioactive molecules viz., heterologous bioactives can be produced by genetically engineered strains of lactic acid bacteria (mostly by lactococci genus). During the last decades, an important effort has been done for the development of tools to use LAB as microbial cell factories for the production of proteins of interest. Given the need to develop effective strategies for the delivery of prophylactic and therapeutic molecules, LAB have appeared as an appealing option for the oral, intranasal, and vaginal delivery of such molecules. So far, these genetically modified organisms have been successfully used as vehicles for delivering functional proteins to mucosal tissues in the treatment of many different pathologies including GIT-related pathologies, diabetes, cancer and viral infections, among others. This chapter covers the role of lactic acid bacteria as a source of probiotics derived from

I. Khan (✉) · S. Ahmad
Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_14

various fermented food products using LAB. It will also cover the raw material processing, value addition, and packaging of such preserved food products.

Keywords:

Lactic acid bacteria · Fermented food · Therapeutics

14.1 Introduction

Almighty God, most pious, most exalted, and most powerful created the globe in a way that the better of which cannot be imagined. Almighty God created the number of creations on the earth started from viruses, nanoorganisms, microorganism, plants, animals, and the creations those considered between the two. The evolution of heterotrophic microorganism in the pool was the first incident of emergence of life. Later, the phototrophic microorganisms evolved during the path of evolution that were capable of synthesizing their own food. Starting from the most primitive type of creations to the most evolved plants and animals, the source of energy remains same, i.e. glucose. The Gram-positive lactobacillus bacteria typically non-sporulating rod or coccus shaped evolved after a long evolutionary path. The lactic acid bacteria have evolved most promising bacteria carrying beneficial health effects on human beings. The lactic acid bacteria (LAB) is being used extensively in the preservation and value addition of food. Improvement of the normal microflora, prevention of infectious diseases and food allergies, reduction of serum cholesterol, anticarcinogenic activity, stabilization of the gut mucosal barrier, immune adjuvant properties, alleviation of intestinal bowel disease symptoms, and improvement in the digestion of lactose in intolerant hosts. The clinical importance of lactic acid bacteria has continuously been exploited in the healthy intestinal functions. Kluyver divided the lactic acid bacteria in two broad classes, i.e. heterofermentative lactic acid bacteria and homofermentative lactic acid bacteria on the basis of metabolic products. The fermentative products of lactic acid bacteria includes either a mixture of lactic acid, carbon dioxide, acetic acid, and/or ethanol. The lactic acid is the major and dominating metabolic end product of fermentation (Priest and Campbell 1996). A variety of lactic acid bacteria viz., *Lactobacillus* species, *Bifidobacterium* sp., *Saccharomyces boulardii*, etc. are proposed as probiotic strains. The live microorganisms given to the patients as food supplement in order to improve the health. The health claims range from rather vague as regulation of bowel activity and increasing of well-being to more specific, such as exerting antagonistic effect on the gastroenteric pathogens *Clostridium difficile*, *Campylobacter jejuni*, *Helicobacter pylori* and rotavirus, neutralizing food mutagens produced in colon, shifting the immune response towards a Th2 response, and thereby alleviating allergic reactions, and lowering serum cholesterol (Ljungh and Wadstrom 2006). Lactic acid bacteria commonly produce antimicrobial substance(s) with activity against the homologous strain. The lactic acid bacteria also produce microbicidal substances with inhibitory effect on gastric and intestinal pathogens. The inhibitory action of microbicidal substances might be due to providing competitive inhibition for cell surface and mucin-binding sites. This could be the expected mechanism of some probiotic strains to inhibit translocation of bacteria from the intestinal region to the liver cells. The protective effects of probiotics against the development of cancerous cells. It can be attributed to mutagens binding by intestinal bacteria, reduction of the enzymes beta-glucuronidase and beta-glucosidase, and deconjugation of bile acids (Ljungh and Wadstrom 2006). The LAB (Lactic acid bacteria) have also been tested in several clinical trials against a number of allergic diseases, and it has been established that probiotics therapy was significantly found to reduce the allergic infections (Żukiewicz-Sobczak et al. 2014). In this chapter, an effort has been made to describe the clinical and therapeutic importance of lactic acid bacteria taken through food sand in pure form.

14.2 Lactic Acid Bacteria and Food

Lactic acid bacteria are commonly known as "probiotics", the living microorganisms which confer health benefits to the human beings (FAO/WHO 2002) and generally used in the production of fermented food products viz., fermented meat products, fermented rice, etc. to extend the shelf life of food and to add functional and sensory properties. Nowadays, fermented meat products being rich in lactobacillus bacteria are employed as a vector for probiotics as no heating is involved during the production of fermented meat products (Ammor and Mayo 2007; De-Vuyst et al. 2008). The preservation activity of lactobacillus bacteria is investigated by several researchers (Buncic et al. 1997; Sakhare and Narasimha Rao 2003) and in many studies it has been observed that lactobacillus bacteria have significant level of antimicrobial activity (Winkowski et al. 1993; Minor-Pérez et al. 2004). But in few cases, negative impact of lactobacillus bacteria has been reported in case of cooked meat products (Blickstad and Molin 1983; Nerbrink and Borch 1993; Bjorkroth and Korkeala 1997; Korkeala and Bjorkroth 1997; Bjorkroth et al. 1998; Borch et al. 1996; Barakat et al. 2000; Samelis and Georgiadou 2000). There are approximately 16 different strains of lactobacillus including major genus viz., *Lactobacillus, Lactococcus, Streptococcus,* and *Leuconostoc* species. It can be found in many different environments, such as fermented foods, and as normal microbiota. Traditional fermented sausage produced with the application of variety of microorganisms such as *Lactobacillus brevis, Lactobacillus plantarum, Pediococcus cerevisiae,* etc. while *Lactobacillus sakei* and *Lactobacillus curvatus* are the most dominating lactic acid bacteria during indigenous fermentation (Hammes et al. 1990). Lactobacillus sakei is a psychrotrophic bacteria generally present on fresh meat and fish and most widely exploited for the production of fermented meat and food safety (Chaillou et al. 2005). The lactic acid bacteria ensure the safety of sausage by inhibiting the growth of harmful Gram-negative pathogenic microorganism viz., pseudomonas (Egan 1983). In a study conducted by Babji and Murthy (2000), it was found that a combination of lactobacillus and low temperature can be a better way to extend the shelf life of meat. *Lactobacillus brevis* is found in food such as sauerkraut and pickles. It is also one of the most common causes of beer spoilage. Ingestion has been shown to improve human immune function, and it has been patented several times. Normal gut microbiota *Lactobacillus brevis* is found in human intestines, vagina, and faeces. Both the strains of bacteria produce lactic acid through heterofermentative pathway of glucose fermentation. *Lactobacillus plantarum* is a non-pathogenic Gram-positive bacterium naturally existing in human saliva and gastrointestinal tract. As a member of the lactic acid bacteria, it is commonly used in food fermentation. Being used as a probiotic, its biotherapeutic applications have been increasingly recognized. Few strains of lactobacillus curvatus have tendency to form phenylethylamine and/or tyramine while lactobacillus sakei does not show such potential (Hammes and Hertel 1996). In a study conducted by Hamasaki et al. (2003), three strains of psychrotrophic lactic acid bacteria viz., *Leuconostoc mesenteroides* subsp. *mesenteroides*, *Lactococcus lactis* subsp. *lactis*, and *Leuconostoc citreum* were isolated from spoiling cooked meat products stored at below 10 °C and the bacterial counts were found to increase to 10^8 CFU/g at 10 °C after 7–12 days. It has been investigated that few meat-borne lactobacilli strains show essential activities like nitrate reductase, nitrite reductase, protease, catalase, and lipase (Hammes et al. 1990). The fermented sausages such as Lebanon bologna, summer sausage, cervelat, thuringer and pepperoni are the most typical examples of dry and semi-dry sausages (Acton et al. 1972). *Lactobacillus brevis* is a Gram-positive, rod-shaped species of lactic acid bacteria which is heterofermentive, creating CO_2 and lactic acid during fermentation. Among the wide category of psychrotrophic lactic acid bacteria enhances the shelf stability of fermented sausage (Egan 1983). The investigations were carried out by Sawitzki et al. (2008) to isolate lactobacillus plantarum AJ2 from naturally fermented sausage and its effects on Milano type salami were investigated. Salami samples were reported with higher values of brightness and redness while no difference in respect of chemical and fatty acid composition were detected. The experiments were conducted (Nguyen et al. 2010) to isolate the selected strains of lactobacillus bacteria for the improved processing of Nem chua, a traditional fermented meat of Vietnam. It has been found that only 44 isolated were confirmed with Gram-positive and catalase-negative activity and showed antimicrobial activity against *Lactobacillus sakei* and *Enterococcus faecium.* The experiments were conducted (Fleck et al. 2012) to identify the lactic acid bacteria isolated from croatian dry fermented sausage which was produced without starter culture under industrial conditions and the investigations indicated the predominance of *Lactobacillus plantarum* followed by *Lactobacillus brevis* among the lactobacillus bacteria. The most commonly isolated lactic acid bacterial strains from fermented sausages are *Lactobacillus plantarum*, *Lactobacillus sakei,* and *Lactobacillus curvatus* (Cocolin et al. 2009, 2004; Ammor et al. 2005; Drosinos et al. 2005). The investigations were carried out (Siddiqui 2012) to assess the probiotics potential of lactic acid bacteria isolated from different food items such as meat, fish, apple, milk, and carrot after two batches of fermentation against most common pathogenic bacteria viz., *Vibrio cholera, Salmonella typhimurium, Escherichia coli, Staphylococcus aureus* and the results showed that lactic acid bacteria isolated from apple revealed positive average inhibitory coefficient against all four pathogens, isolated from milk and carrot showed positive average inhibitory coefficient against three pathogens each and isolates from meat and fish reported with positive average inhibitory coefficient against two pathogens. In the research, it is also concluded that among 29 isolated, 17 were found effective against *Escherichia coli*, 11 against *Salmonella typhimurium*, 11 against *Staphylococcus aureus,* and 13 bacterial isolated were found effective against *Vibrio cholera*. The lactic acid bacteria isolated from milk, apple, and carrot were reported as the most potential probiotics against targeted pathogens. The studies were conducted by Tsuda et al. (2012) to select the lactobacillus bacteria strains for fermented meat products and screened their tolerance level in gastrointestinal tract. Five strains of lactobacillus bacteria were isolated from traditional fermented fish product (Funazushi) in japan and *Lactobacillus plantarum* JAB2001 strain found to show significant tolerance against bile juice as well as 10% sodium chloride and also reported to induce production of gastrointestinal juices. Sometimes, the lactic acid bacteria switch their pathway to heterofermentative pathway in which acetic acid and carbon dioxide production also take place along with lactic acid production. Kamenik et al. (2013) found that the amount of acetic acid production reported higher (24.28–67.41 μmol g^{-1} dry matter) than the lactic acid production (20.98–-29.02 μmol g^{-1} dry matter) during heterofermentation pathway. During the production of fermented meat products, the growth and activity of lactic acid bacteria depends upon a number of physical and biochemical parameters which is studied by Hayek and Ibrahim (2013) and discussed the limitations and challenges of lactic acid bacteria for the production of fermented food products. They concluded that availability of nutrients viz., sugars, free amino acids, peptides, minerals, vitamins along with buffering agents are the important factors that affect the growth of lactic acid bacteria. It is studied that only few nutritional parameters can be regulated rather than all the parameters at a time. It has been studied by many researchers that lactic acid bacteria show antagonistic effect on the growth of pathogenic microorganisms such as *Listeria monocytogenes,* the most deadly pathogen for human beings. Silins (2014) performed the experiments and established the most interesting correlation among lactic acid bacteria, water activity, pH, and survival of *Listeria monocytogenes* in fermented sausages. They found that low pH, low water activity, and high count of lactic acid bacteria showed antagonistic effect on the growth of *Listeria monocytogenes.* Maksimovic et al. (2015) conducted the studies to find out the contribution of lactic acid bacteria in the production of traditional dry sausage from meat of wild or domestic animals. They advocated that lactic acid bacteria pose number of beneficial effects in meat including assurance of food safety by producing antimicrobial compounds. Ehrmann et al. (2016) conducted the study on pork salami and isolated a novel strain of lactobacillus bacteria, i.e. *Lactobacillus insicii* sp. nov. supported by the specific phenotypic characteristics and phylogenetic analysis of 16 s RNA gene sequence. The species is different from the other most common meat-associated microbes. Mokoena et al. (2016) conducted the study to isolate the potential probiotics lactobacillus bacteria from African traditional fermented foods and beverages. They claimed that isolated lactobacillus bacteria were found with potential therapeutic and antimicrobial properties which could be exploited for the welfare of human beings. The role of *Lactobacillus* bacteria for the preservation of food was thoroughly reviewed by Hitendra et al. (2016), and they concluded that lactobacillus bacteria show a number of beneficial health effects with no pathogenic record as per the recent scientific evidences. Erturkmen et al. (2016) conducted the studies on utilization of lactobacillus bacteria on meat products. They stated that growing demand of safe and healthy meat products induced the application of lactobacillus bacteria which add probiotics property in meat products. The studies were conducted by Aquilanti et al. (2016) on dry fermented sausages manufactured by Italy, Greek, and French to find the microbial flora of the sausage. Investigations suggest the dominancy of facultative heterofermentative lactobacillus bacteria (mainly psychrotrophic species *Lactobacillus sakei* and *Lactobacillus curvatus*) along with coagulase-negative cocci (mainly *Staphylococcus xylosus*) in dry fermented sausages. Phan et al. (2017) conducted the study to find out the diversity of lactobacillus bacteria in naturally fermented vegetable and meat-based food products in the central region of Vietnam. The dominant lactobacillus bacteria in vegetable-based products are *Lactobacillus helveticus*, *Lactobacillus fermentum,* and *Lactobacillus plantarum* while in meat-based products the major lactic acid bacteria were *Weissella cibaria, Pediococcus pentosaceus*, and *Lactococcus lactis.* Castellano et al. (2017) conducted a pathogen biocontrol strategy analysis on lactic acid bacteria in ready to eat (RTE) meat products and they found that lactic acid bacteria being a GRAS organism offer a valuable opportunity to make pathogen free foods. The application of bacteriocin produced by LAB exploiting for the inactivation of pathogenic bacteria such as *Listeria monocytogenes.* The investigations were carried out by Rzepkowska et al. (2017) to assess the safety and antimicrobial properties of lactic acid bacteria viz., lactobacillus and Pediococcus strains isolated from polish raw fermented meat products. The strains were found resistant to gastric enzymes, intestinal enzymes, and bile juice. Out of 25 strains, most of them were found resistant against gentamycin, streptomycin, vancomycin, tetracycline, kanamycin, and ciprofloxacin. Three strains (Lb. brevis BAL1, BAL10, and KL5) were found unsafe due to the production of β-glucuronidase and seven strains were reported with bacteriocin producing property. *Lactobacillus brevis* SCH6, *Pediococcus pentosaceus* BAL6, and KL14 strains were found superior in terms of safety and antimicrobial property. Dincer and Kivanc (2018) conducted the experiments to investigate the lipolytic activity of lactic acid bacteria isolated from Turkish pastirma. Out of total 50 strains of lactic acid bacteria, only 25 LAB strains were found to show lipolytic activity. *Lactobacillus plantarum* reported with highest lipolytic activity among the strains. A review study was performed by Admassie (2018) on food fermentation and importance of biotechnology for the development of a number of food properties by metabolic engineering of lactic acid bacteria according to the need. He also listed the role of biotechnology to evolve modern food/feed fermentation technology (Fig. 14.1).

14.3 Lactic Acid Bacteria as Probiotics Agents

Probiotics are live microorganisms including bacteria and yeast that provide health benefits to the host when ingested in adequate amounts. The strains most frequently used as probiotics include lactic acid bacteria and bifidobacteria. Probiotics improve human health by augmenting the functioning of digestive system. The term

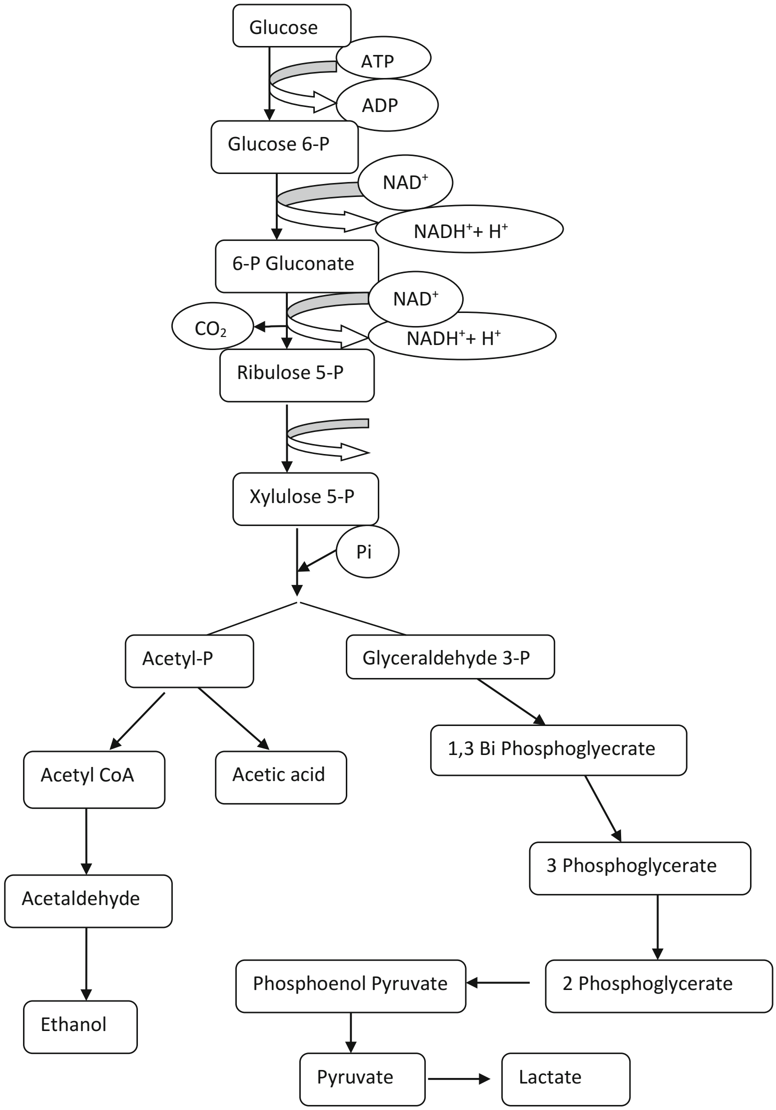


Fig. 14.1 Biochemical pathway of lactic acid production by lactic acid bacteria

"probiotics" was derived from Greek words pro and biotos and translated as "for life" and primarily was used in antagonistic sense of antibiotic. Following recommendations of an FAO/WHO (2002) working group on the evaluation of probiotics in food, probiotics, are live microorganisms that, when administered in adequate amounts, confer a health benefit on the host (Sanders 2008; Schrezenmeir and De Vrese 2001). The use of live bacteria by human beings has been proven since over 2000 years back. Nevertheless, the work of Metchnikoff (1908) first placed probiotics on a scientific basis at the beginning of this century. Metchnikoff hypothesized the importance of probiotics by experimenting the effects of sour milk on the human gut in a positive sense. The initial use of probiotics has been reported by Kollath (1953), who claimed the restoration of the health of malnourished patients by different organic and inorganic supplements. After few months, Vergin (1954) also advocated the beneficial effects of probiotics in treating the microbial imbalance problems caused by antibiotic therapy. Similarly, Kolb recognized detrimental effects of antibiotic therapy and proposed the prevention by probiotics (Vasiljevic and Shah 2008). The probiotics also defined as the "microorganisms promoting the growth of other microorganisms" by Lilly and Stillwell (1965). Metchnikoff suggested that lactobacilli should be able to combat intestinal putrefaction and contribute to long and sustainable life of human beings. These microorganisms may not actually be residents of the intestine but they should have a "beneficial effect on the general and health status of humans and animals" (Holzapfel et al. 2001; Belhadj et al. 2010). The dead microbes, however, are not probiotics irrespective of usability (Sanders 2008). Probiotics are known in relation to nutrition as "viable preparations in foods or dietary supplements to improve the health of humans and animals".

14.3.1 Mechanism of Probiotics Action

The mechanisms of action are not widely proven, in vitro and some in vivo experiments support several (Reid 2016). Ultimately, the goal of any field or product is to be understood by lay people and experts alike. Probiotics have come a long way in 100 years since Metchnikoff and 10 years since their globalization, but their evolution is far from over. Although therapeutic alternatives for a variety of diseases, probiotics have shown significant potential, but the mechanisms responsible for these results have not yet been completely elucidated (Bermudez-Brito et al. 2012). The action mechanism of antagonistic effects of probiotics on different microorganisms include competitive adherence to the mucosa and epithelium, the modification of the intestinal microbiota, strengthening of the gut epithelial barrier, and modulation of the immune system to convey an advantage to the host. Probiotics communicate with the host through pattern recognition receptors, such as toll-like receptors and nucleotide-binding oligomerization domain-containing protein-like receptors, which modulate key signalling pathways, such as nuclear factor-κB and mitogen-activated protein kinase, to enhance or suppress activation and influence downstream pathways (Bermudez-Brito et al. 2012). This understanding is important to obtain measured antimicrobial response with minimal damage to inflammatory tissue. This understanding of probiotic mechanisms will pave the path for selection of appropriate probiotic strain for particular case and consequently it may also unveil the novel probiotic functions (Bermudez-Brito et al. 2012) (Fig. 14.2).

The main mechanisms of probiotic action include strengthening of the epithelial barrier, enhanced adhesion to intestinal mucosa, and concomitant inhibition of pathogen adherence, competitive exclusion of pathogenic microorganisms,

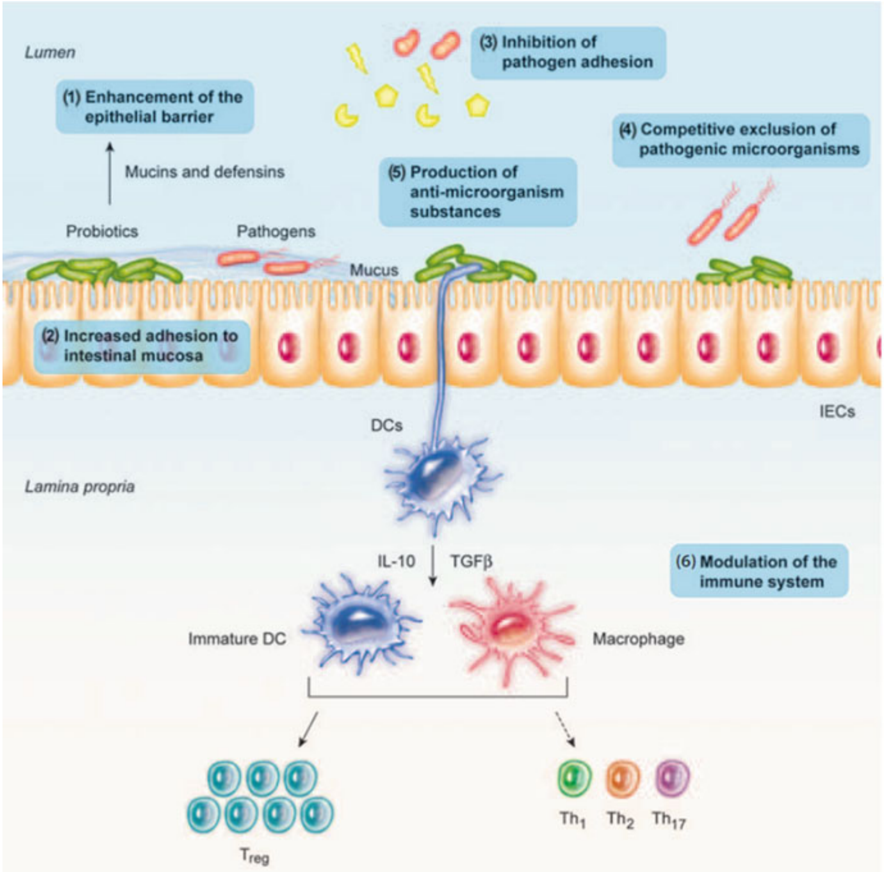


Fig. 14.2 Mechanism of probiotics action (Bermudez-Brito et al. 2012)

production of antimicrobial substances and immune system modulation (Bermudez-Brito et al. 2012). The majority of lactic acid bacteria produce antimicrobial peptides such as bacteriocins, nicin, and small molecular weight antimicrobial peptides. A variety of bacteriocins produced by different Gram-positive bacteria viz., lactacin B by *L. acidophilus*, plantaricin by *L. plantarum*, and nisin produced by *Lactococcus lactis*. Unlike the broad spectrum antibiotics, the bacteriocins have narrow spectrum activity and act only against closely related bacteria, but some bacteriocins are also active against food-borne pathogens (Nielsen et al. 2010).

Popular mechanisms of bacteriocin-mediated killing include the destruction of target cells by pores formation and/or inhibition of cell wall synthesis (Hassan et al. 2012). Nisin inhibits cell wall biosynthesis of spore-forming bacilli by forming complex with the ultimate cell wall precursor, lipid II. Subsequently, the complex aggregates and incorporates peptides to form a pore in the bacterial membrane (Bierbaum 2009).

14.4 Allergies and Probiotics Therapy

The risk of food allergy diseases is rising throughout the world. The management practice is to prevent allergens and treat symptomatically. The probiotics have been reported to be helpful for food allergy treatment and prevention (Tan-Lim and Esteban-Ipac 2018). The lactic acid bacteria have been proved as potential therapeutic agents for human beings. They have been found to modify the intestinal microflora of human digestive system. The probiotics term refers the health promoting living microorganism, specifically in context of lactic acid bacteria. The prophylactic administration of probiotics during early stages of human babies is crucial and boost the immunity of babies. At the early stage of life, the intestine of babies lacks the microflora which results in disturbed digestive system of babies. Perhaps this is the reason why paediatrician recommends the probiotics dose to normalize the digestive system. Probiotics, due to their immunomodulatory properties and safety of use, are a good, natural alternative for the prevention and treatment of many diseases. The probiotics therapy is also given to the allergic patients for the treatment and prevention of allergic problems in future (Żukiewicz-Sobczak et al. 2014). Today, allergic problems are very common and it covers around 30-40% of the world population. The allergic rhinitis affects around 10–30% of the population worldwide. While the sensitization of Ig E antibody to the foreign proteins in the environment has been detected in 40% of the world population (AAAAI 2019). In the current scenario, the drug allergies have now become so common that it affects 10% and 20% of world population and hospitalized population, respectively (AAAAI 2019). The American academy of allergy asthma and immunology estimated up to 20% fatalities due to anaphylaxis. Increasing the allergic problems in the society somewhere is the result of polluted climatic conditions. The forbidden human activities are responsible for the problem and people do not bother even their own health. Among the various category of allergic, the allergic rhinitis is one of the most prevalent types of allergy. In recent decades, the incidence of allergic rhinitis is increasing every year. Allergic rhinitis is a distorted immune response to the common antigens in the nasal mucosa. The current available therapies are not satisfactory and can cause a variety of complications. The latest findings have been shown to pave the path in treating allergic rhinitis (Yang et al. 2013). The types of probiotics using in the treatment of allergic rhinitis, approaches of administration, its safety, mechanisms of action, treating results, and the perspectives to improve effectiveness of probiotics in the treatment of allergic rhinitis. Though probiotics are a useful therapeutic remedy in the treatment of allergic rhinitis, but its underlying mechanisms remain to be further investigated.

14.5 Probiotics and Immune Response

It is the most established fact that probiotics bacteria can exert an immunomodulatory effect. The probiotics are capable of interacting with epithelial cells, dendritic cells (DCs) and with monocytes/macrophages along with lymphocytes. The immune system has been categorized between the innate and adaptive systems. The innate immune system responds to common structures called pathogen-associated molecular patterns (PAMPs) shared by the vast majority of pathogens. In contrast, the adaptive immune response depends on B and T lymphocytes, which is very specific for particular antigens. (Gomez-Llorente et al. 2010). The initial response against pathogens is activated by pattern recognition receptors (PPRs) that bind with pathogen-associated molecular patterns (PAMPs). A lot of research has been conducted on pattern recognition receptors. These receptors typically are toll-like receptors (TLRs). Along with pattern recognition receptors, intracellular nucleotide-binding oligomerization domain-containing protein (NOD)-like receptors (NLRs) and extracellular C-type lectin receptors (CLRs) are known to transmit signals upon interaction with bacteria (Lebeer et al. 2010). It is well founded that intestinal epithelial cells (IECs) are the host cells that interact with probiotics. Furthermore, probiotics can encounter dendritic cells (DCs) that play a major role in innate and adaptive immunity. Both IECs and DCs can respond to gut microorganisms by reacting through their pattern recognition receptors (Gomez-Llorente et al. 2010; Lebeer et al. 2010). Probiotics can also cause qualitative changes in intestinal mucins that prevent binding of pathogen (Kim and Ho 2010).

14.6 Probiotics: Future Prospects

It is the very famous quote that prevention is better than treatment. Today, the consumers have become conscious about their health and more inclined towards the safety and healthy aspects of food irrespective of the cost. Increasing consequences of drugs use, it is essential to take healthy foods for the prevention of diseases. It is expected that in the coming future, the patient will be treated with food rather than medicines. With increasing consumer awareness programme, people have come to know about the importance of probiotics. As the data suggests that probiotics has potential therapeutic effect on human health by preventing and treating the several non-communicable diseases listed in Table 14.1. No doubt, the future of market players involved in probiotic industry is bright. The industry is continuously putting its efforts to make bioavailable form of probiotics with the amalgamation of emerging technologies including nanotechnology.

14.7 Conclusion

The fermented foods have now become popular and the choice of consumers on health grounds worldwide. The variety of lactic acid bacteria added in fermented foods to provide beneficial health effects, taste, flavour along with preservative effect. The lactic acid bacteria have been proved to show potential therapeutic effects for prevention and treatment of various non communicable diseases such as allergic reactions, immune-deficiency disorders, and gastrointestinal disorders. Nevertheless, many probiotics food health claims have not yet been substantiated by

Table 14.1 Therapeutic importance of lactic acid bacteria (Leroy et al. 2008)

Health claims of LAB	Proposed mechanism(s)
Prevention of cancer	Enhancement of immune function, influence on bile salt concentrations, suppression of growth of procarcinogenic bacteria, reduction of the absorption of carcinogens, production of anti-mutagenic, binding/inactivation of mutagenic compounds, inhibition of the transformation of pro-carcinogens into active carcinogens
Management and prevention of atopic diseases	Immune response modulation
Control of irritable bowel syndrome	Modulation of gut microbiota and reduction of intestinal gas production
Management of inflammatory bowel diseases (Crohn's disease, ulcerative colitis, pouchitis)	Modulation of immune response, modulation of gut Microbiota
Prevention of urogenital tract disorders	Production of antimicrobial substances, competition for adhesion sites, competitive exclusion of pathogens
Prevention of heart diseases/influence on blood cholesterol levels	Assimilation of cholesterol by bacterial cells, deconjugation of bile acids by bacterial acid hydrolases, cholesterol binding to bacterial cell walls, reduction of hepatic cholesterol synthesis, and/or redistribution of cholesterol from plasma to liver through influence of the bacterial production of short-chain fatty acids
Prevention/treatment of *Helicobacter pylori* infections	Production of antimicrobial substances, stimulation of the mucus secretion, competition for adhesion sites, stimulation of specific and nonspecific immune responses
Relief of lactose indigestion Shortening of colonic transit Time	Action of bacterial β-galactosidase(s) on lactose Influence on peristalsis through bacterial metabolite production

experimental evidence. Furthermore, the probiotics efficacy for one type of lactic acid bacteria cannot be correlated with other probiotic strains. Moreover, the mechanisms underlying probiotics action have not yet been fully elucidated.

References

Acton JC, Williams JG, Johnson JG (1972) Effect of fermentation temperature on changes in meat properties and flavor of summer sausage. Milk Food Technol 35(5)

American Academy of allergy asthma and immunology (2019) Probiotics and allergic reactions. www.aaaai.org

Ammor MS, Mayo B (2007) Selection criteria for lactic acid bacteria to be used as functional starter cultures in dry sausage production: An update. Meat Sci 76:138–146

Ammor S, Rachman C, Chaillou S, Revost H, Dousset X, Zagorec M, Doufour E, Chavallier I (2005) Phenotype and genotype identification of lactic acid bacteria isolated from a small-scale facility producing traditional dry sausages. Food Microbiol 22:373–382

Aquilanti L, Garofalo C, Osimani A, Clementi F (2016) Ecology of lactic acid bacteria and coagulase negative cocci in fermented dry sausages manufactured in Italy and other Mediterranean countries: an overview. Int Food Res J 23(2):429–445

Babji Y, Murthy TRK (2000) Effect of inoculation of mesophilic lactic acid bacteria on microbial and sensory changes of minced goat meat during storage under vacuum and subsequent aerobic storage. Meat Sci 54(2):197–202

Barakat RK, Griffiths MW, Harris LJ (2000) Isolation and characterization of Carnobacterium, Lactococcus, and Enterococcus spp. from cooked, modified atmosphere packaged, refrigerated, poultry meat. Int J Food Microbiol 62:83–94

Belhadj H, Harzallah D, Khennouf S, Dahamna S, Bouharati S, Baghiani A (2010) Isolation, identification and antimicrobial activity of lactic acid bacteria from Algerian honeybee collected pollen. Acta Hort (ISHS) 854:51–58

Bermudez-Brito M, Plaza-Diaz J, Muñoz-Quezada S, Gómez-Llorente C, Gil A (2012) Probiotic mechanisms of action. Ann Nutr Metab 61:160–174

Bierbaum G (2009) Sahl: Lantibiotics: mode of action, biosynthesis and bioengineering. Curr Pharm Biotechnol 10:2–18

Bjorkroth KJ, Korkeala HJ (1997) Use of rRNA gene restriction patterns to evaluate lactic acid bacterium contamination of vacuum-packaged sliced cooked whole-meat product in a meat processing plant. Appl Environ Microbiol 63:448–453

Bjorkroth KJ, Vandamme P, Korkeala HJ (1998) Identification and characterization of Leuconostoc carnosum, associated with production and spoilage of vacuum-packaged, sliced, cooked ham. Appl Environ Microbiol 64:3313–3319

Blickstad E, Molin G (1983) The microbial flora of smoked pork loin and frankfurter sausage stored in different gas atmospheres at 4°C. J Appl Bacteriol 54:45–56

Borch E, Kant-Muermans ML, Blixt Y (1996) Bacterial spoilage of meat and cured meat products. Int J Food Microbiol 33:103–120

Buncic S, Avery SM, Moorhead SM (1997) Insufficient antilisterial capacity of low inoculums Lactobacillus cultures on long-term stored meats at 4°C. Int J Food Microbiol 34(2):157–170

Castellano P, Ibarreche MP, Massani MB, Fontana C, Vignolo GM (2017) Strategies for pathogen biocontrol using lactic acid bacteria and their metabolites: a focus on meat ecosystems and industrial environments. Microorganisms 2017(5):38. https://doi.org/10.3390/microorganisms5030038

Chaillou S et al (2005) The complete genome sequence of the meat-borne lactic acid bacterium Lactobacillus sakei 23K. Nat Biotechnol 23(12):1527–1533

Cocolin L, Dolci P, Rantsiou K, Urso R, Cantoni C, Comi G (2009) Lactic acid bacteria ecology of three traditional fermented sausages produced in the North of Italy as determined by molecular methods. Meat Sci 82:125–132

Cocolin L, Rantsiou K, Iacumin L, Urso R, Cantoni C, Comi G (2004) Study of the ecology of fresh sausages and characterisation of populations of lactic acid bacteria by molecular methods. Appl Environ Microbiol 4:1883–1894

De-Vuyst L, Falony G, Leroy F (2008) Probiotics in fermented sausages. Meat Sci 80:75–78

Dincer E, Kivanc M (2018) Lipolytic activity of lactic acid bacteria isolated from Turkish Pastirma. Anadolu Univ J Sci Technolol 7(1)

Admassie M (2018) A review on food fermentation and the biotechnology of lactic acid bacteria. World J Food Sci Technol 2(1):19–24

Drosinos EH, Mataragas M, Xiraphi N, Moschonas F, Gaitis G, Metaxopoulos J (2005) Characterisation of the microbial flora from a traditional Greek fermented sausage. Meat Sci 69:307–317

Egan AF (1983) Lactic acid bacteria of meat and meat products. Antonie Van Leeuwenhoek 49:327–336

Ehrmann MA, Krockel L, Lick S, Radmann P, Bantleon A, Vogel RF (2016) Lactobacillus insicii sp. nov., isolated from fermented raw meat. Int J Syst Evol Microbiol 66:236–242

Erturkmen P, Kilic GB, Kilic B (2016) Utilization of lactic acid bacteria and probiotics on meat products. J Hygienic Eng Design 15:78–82

FAO/WHO (2002) Guidelines for the evaluation of probiotics in food. Report of a joint venture of FAO and WHO working group on drafting guidelines for the evaluation of probiotics in food. Ontario, London

Fleck ZC, Savic V, Kozacinski L, Njari B, Zdolec N, Filipovic I (2012) Identification of lactic acid bacteria isolated from dry fermented sausages. A Veterinarski Archiv 82(3):265–272

Gomez-Llorente C, Muñoz S, Gil A (2010) Role of Toll-like receptors in the development of immunotolerance mediated by probiotics. Proc Nutr Soc 69:381–389

Hamasaki Y, Ayaki M, Fuchu H, Sugiyama M, Morita H (2003) Behavior of Psychrotrophic lactic acid bacteria isolated from spoiling cooked meat products. Appl Environ Microbiol 69:3668–3671

Hammes WP, Hertel C (1996) Selection and improvement of lactic acid bacteria used in meat and sausage fermentation. Lait 76:159–168

Hammes WP, Bantleon A, Min S (1990) Lactic acid bacteria in meat fermentation. FEMS Microbiol Lett 87(1–2):165–173

Hassan M, Kjos M, Nes IF, Diep DB, Lotfipour F (2012) Natural antimicrobial peptides from bacteria: characteristics and potential applications to fight against antibiotic resistance. J Appl Microbiol. https://doi.org/10.1111/j.1365-2672.2012.05338

Hayek SA, Ibrahim SA (2013) Current limitations and challenges with lactic acid bacteria: a review. Food Nutr Sci 2013(4):73–87. https://doi.org/10.4236/fns.2013.411A010

Hitendra J, Prasad BDN, Gurumurthy H, Suvarna VC (2016) Role of lactic acid bacteria (LAB) in food preservation. Int J Curr Microbiol Appl Sci 5(8):255–257

Holzapfel WH, Haberer P, Geisen R, Björkroth J, Schillinger U (2001) Taxonomy and important features of probiotic microorganisms in food nutrition. Am J Clin Nutr 73:365S–373S

Kamenik J, Duskova M, Salakova A, Sedo O (2013) Heterofermentative process in dry fermented sausages—a case report. Acta Vet Brno 2013(82):181–186. https://doi.org/10.2754/avb201382020181

Kim YS, Ho SB (2010) Intestinal goblet cells and mucins in health and disease. Curr Gastroenterol Rep 12(5):319–330. https://doi.org/10.1007/s11894-010-0131-2

Kollath W (1953) Ernährung und Zahnsystem. Dtsch Zahnarztl Z 8:7–16

Korkeala HJ, Bjorkroth KJ (1997) Microbiological spoilage and contamination of vacuum-packaged cooked sausages. J Food Prot 60:724–731

Lebeer S, Vanderleyden J, De Keersmaecker CJ (2010) Host interactions of probiotic bacterial surface molecules: comparison with commensals and pathogens. Nat Rev Microbiol 8:171–184

Leroy F, Falony G, de Vuyst L (2008) Latest developments in probiotics. In: Toldrà F (ed) Meat biotechnology. Springer Science+Business Media, New York, pp 217–229

Lilly DM, Stillwell RH (1965) Probiotics: growth promoting factors produced by microorganisms. Science 147:747–748

Ljungh A, Wadstrom T (2006 Sep) (2006) Lactic acid bacteria as probiotics. Curr Issues Intest Microbiol 7(2):73–89

Maksimovic Z, Hulak AN, Vuko M, Kovacevic V, Kos I, Fuka MM (2015) Lactic acid bacteria in traditional dry sausage production. MESO XVII

Metchnikoff E (1908) The prolongation of life. G.P. Putnam, New York, 376 p

Minor-Pérez H, Ponce-Alquicira E, Macíasbravo S, Guerrero-Legarreta I (2004) Changes in fatty acids and microbial populations of pork inoculated with two biopreservative strains. Meat Sci 66 (4):793–800

Mokoena MP, Mutanda T, Olaniran AO (2016) Perspectives on the probiotic potential of lactic acid bacteria from African traditional fermented foods and beverages. Food Nutr Res 60:29630. https://doi.org/10.3402/fnr.v60.29630

Nerbrink E, Borch E (1993) Evaluation of bacterial contamination at separate processing stages in emulsion sausage production. Int J Food Microbiol 20:37–44

Nguyen HTH, Elegado FB, Librojo-Basilio NT, Mabesa RC, Dizon EI (2010) Isolation and characterisation of selected lactic acid bacteria for improved processing of Nem chua, a traditional fermented meat from Vietnam. Benefic Microbes 1(1):67–74

Nielsen DS, Cho GS, Hanak A, Huch M, Franz CM, Arneborg N (2010) The effect of bacteriocin-producing Lactobacillus plantarum strains on the intracellular pH of sessile and planktonic Listeria monocytogenes single cells. Int J Food Microbiol 141:S53–S59

Phan YTN, Tang MT, Tran TTM, Nguyen VH, Nguyen TH, Tsuruta T, Nishino N (2017) Diversity of lactic acid bacteria in vegetable-based and meat-based fermented foods produced in the central region of Vietnam. AIMS Microbiol 3(1):61–70. https://doi.org/10.3934/microbiol.2017.1.61

Priest FG, Campbell I (1996) Brewing microbiology, 2nd edn. Chapman & Hall, London, pp 134–156

Reid G (2016) Probiotics: definition, scope and mechanisms of action. Best Pract Res Clin Gastroenterol 30(1):17–25

Rzepkowska A, Zielińska D, Oldak A, Kołożyn-Krajewska D (2017) Safety assessment and antimicrobial properties of the lactic acid bacteria strains isolated from polish raw fermented meat products. Int J Food Prop 20(11):2736–2747. https://doi.org/10.1080/10942912.2016.1250098

Sakhare PZ, Narasimha Rao D (2003) Microbial profiles during lactic fermentation of meat by combined starter cultures at high temperatures. Food Control 14(1):1–5

Samelis J, Georgiadou KG (2000) The microbial association of Greek taverna sausage stored at 4 and 10 degrees C in air, vacuum or 100% carbon dioxide, and its spoilage potential. J Appl Microbiol 88:58–68

Sanders ME (2008) Probiotics: definition, sources, selection, and uses. Clin Infect Dis 46:S58–S61

Sawitzki MC, Fiorentini AM, Junior AC, Bertol TM, Santanna ES (2008) Lactobacillus plantarum AJ2 isolated from naturally fermented sausage and its effects on the technological properties of Milano-type salami. Ciênc Tecnol Aliment 28(3):709–717

Schrezenmeir J, De Vrese M (2001) Probiotics, prebiotics, and symbiotics—approaching a definition. Am J Clin Nutr 73:361S–364S

Siddiqui NI (2012) Prevalence and trends of obesity in Indian school children of different socio-economic class. Indian J Basic Appl Med Res 2(5):393–398

Silins I (2014) The effects of pH, aW, and lactic acid bacteria on *Listeria monocytogenes* in fermented sausages. Paper presented at the 9th Baltic Conference on Food Science and Technology" Food for Consumer Well-Being" FOODBALT 2014, Jelgava, Latvia, 8–9 May, 2014

Tan-Lim CSC, Esteban-Ipac NAR (2018) Probiotics as treatment for food allergies among pediatric patients: a meta-analysis. World Allergy Organ J 11:25. https://doi.org/10.1186/s40413-018-0204-5

Tsuda H, Matsumoto T, Ishimi Y (2012) Selection of lactic acid bacteria as starter cultures for fermented meat products. Food Sci Technol Res 18(5):713–721

Vasiljevic T, Shah NP (2008) Review: probiotics—from Metchnikoff to bioactives. Int Dairy J 18:714–728

Vergin F (1954) Anti- and probiotika. Hippokrates 25:16–19

Winkowski K, Crandall AD, Montville TJ (1993) Inhibition of Listeria monocytogenes by Lactobacillus bavaricus MN in beef systems at refrigeration temperatures. Appl Environ Microbiol 59 (8):2552–2557

Yang G, Liu ZQ, Yang PC (2013) Treatment of allergic rhinitis with probiotics: an alternative approach. North Am J Med Sci 5(8):465–468

Żukiewicz-Sobczak W, Wróblewska P, Adamczuk P, Silny W (2014) Probiotic lactic acid bacteria and their potential in the prevention and treatment of allergic diseases. Central Eur J Immunol 2014:39(1)

Flavonoids: Health Benefits and Their Potential Use in Food Systems

15

Arshied Manzoor, Ishfaq Hamid Dar, Shayeeb Ahmad Bhat, and Saghir Ahmad

Abstract

In the mid-1980s, the term "functional foods" was introduced in Japan with the definition of processed foods comprising ingredients that assist or succor body functions besides nutrition. Likewise, flavonoids being highly bioactive may too fall in the category of functional foods because of their valuable antioxidant and color furnishing property in addition to anti-inflammatory health functions. Flavonoids are a class of phytonutrients, derived its name from Latin word *flavus* due to their color-related property, which means "yellow." Flavonoids are contemplated to be one of the largest nutrient families known to scientists, as more than 6000 family members of flavonoids have been reported in studies so far. Some of the promising members comprising flavonoids include quercetin, kaempferol, catechins, and anthocyanidins. Flavonoids are obtained in hefty amounts from plant sources, especially fruits and vegetables as compared to animal sources. The aim of this chapter is to present a basic review of nature, various sources, structure, and chemistry of action of flavonoids. The digestion, absorption, and finally metabolization of a fraction of a particular nutrient along the normal pathways depict its bioavailability. This chapter also addresses the bioavailability of flavonoids, being the major issue of the aforesaid flavonoids. Moreover, this chapter presents a simplified overview of the antimicrobial effects and various foods developed after the incorporation of flavonoids. Furthermore, classification and the antioxidant activity of some classes will be covered. The chapter will also explore their potential use in food systems for providing functional foods.

A. Manzoor (✉) · I. H. Dar · S. A. Bhat · S. Ahmad
Faculty of Agricultural Sciences, Department of Post Harvest Engineering and Technology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4_15

Keywords

Flavonoids · Health benefits · Functional foods · Bioavailability · Antioxidant activity

15.1 Introduction

In 1936, Rusnyak and Szent Gyorgyi isolated the first characterized bioflavonoid “citrin” from the peels of lemon. Due to their property of membrane permeability, they called it “vitamin P” though this vitamin status was later revoked (Bentsáth et al. 1936). Flavonoids are having a direct association with the human health and dietary ingredients; hence, researchers have shown a lot of interest towards flavonoids from plant sources. Moreover, the configuration, number of hydroxyl groups, and the functional groups attached to flavonoids decide their bioavailability, metabolism, and biological activity (Kumar and Pandey 2013). Flavonoids, a group of plant pigments bestowed with variable phenolic structures, synthesized from phenylalanine, are generally found in fruits, vegetables, roots, barks, flowers, tea, propolis, and honey and wine (Harborne 2017). As of now, almost 6000 flavonoids have been reported constituting the colorful pigments of fruits, herbs, vegetables, and medicinal plants (Panche and Diwan 2016). Some of the medicinal and dietary plants rich in flavonoids are summarized in Table 15.1.

Flavonoids are potent growth enhancers coupled with plaque-resistant properties in vegetables they are a part of (Havsteen 2002). In addition to the vast diaspora in health-promoting effects, they are depicted to have favorable biochemical and antioxidant effects in combating the diseases like cancer, Alzheimer’s disease (AD), atherosclerosis, etc. (Castañeda-ovando et al. 2009). Flavonoids are a class of low-molecular-weight phenolic compounds more or less distributed in every part of the plants constituting the plant kingdom (Dewick 2009). Flavonoids with the eccentric major sources such as onion and tea are divided into subgroups, including chalcones, flavones, flavonols, and isoflavones. Some of the degraded products of flavonoids, mostly phenolic acids, are also potent radical-scavengers after ingestion. Studies have also revealed a negative correlation of flavonoids in citrus fruits with the risk of coronary heart and degenerative diseases (De Moraes Barros et al. 2012).

Owing to flavonoid features such as less water solubility, low absorption, and short residence time in intestine, the toxic effects of flavonoids are positively defied since their therapeutic effectiveness is a function of solubility. However, there may be an occasional allergy. No doubt, this is a worthy property of flavonoids but when it comes to their medicinal use, it actually is a drawback. Hence, semi-synthetic and water-soluble flavonoids such as hydroxyethylrutosides and inositol-2-phosphatequercetin for the treatment of hypertension and microbleeding are developed (Havsteen 2002).

Table 15.1 Some major flavonoids from dietary and medicinal sources

Flavonoid type	Class	Dietary/Medicinal plant source	References
(+)-Catechin (−)-Epicatechin Epigallocatechin	Flavanol	Tea	López et al. (2001)
Kaempferol, quercetin, myricetin, and tamarixetin	Flavonol	Onion, red wine, olive oil, berries, and grapefruit	Stewart et al. (2000), Hertog et al. (1992)
Genistin, daidzein	Isoflavone	Soybean	Reinli and Block (1996)
Quercetin-3-*O*-rutinoside		Citrus fruits, *Bauhinia monandra*[a] (Fabaceae)	Avula et al. (2010)
Kaempferol glycosides	Flavonol	*Acalypha indica*[a] (Euphorbiaceae)	Lopez-Lazaro (2008)
Quercetin	Flavonol	*Betula pendula*[a] (Betulaceae)	Gupta et al. (1983)
Vitexin	Flavone	*Passiflora incarnate*[a] (Passifloraceae)	Gupta et al. (1983)
Hyperoside	Flavonol	*Tilia cordata*[a] (Tiliaceae)	Gupta et al. (1983)
Pongaflavanol	Flavanol	*Pongamia pinnata*[a] (Fabaceae)	Agarwal and Kamal (2007)
Luteolin-7-O-glycoside	Flavone	*Mentha longifolia*[a] (Lamiaceae)	Kogawa et al. (2007)
Apigeninidin, cyanidin	Anthocyanidin	Cherry, raspberry, and strawberry	Hertog et al. (1992)
Chrysin, apigenin, rutin, luteolin, and luteolin glucosides	Flavone	Fruit skins, red wine, buckwheat, red pepper, and tomato skin	Stewart et al. (2000)
Luteolin	Flavone	*Aloe vera*[a] (Asphodelaceae)	Lopez-Lazaro (2008)
(+)-Catechin	Flavanol	Brysonimacrassa[a] (Malphigaceae)	Aderogba et al. (2006)
Isorhamnetin	Flavonol	*Calendula officinalis*[a] (Compositae)	Gupta et al. (1983)
3,4-Methlenedioxyflavone	Flavone	*Limnophila indica*[a] (Scrophulariaceae)	Sannomiya et al. (2005)
Purpurin		*Tephrosia purpurea*[a] (Fabaceae)	Sannomiya et al. (2005)
Luteolin	Flavone	*Momordica charantia*[a] (Cucurbitaceae)	Ghoulami et al. (2001)
Chrysin	Flavone	*Oroxylum indicum*[a] (Bignoniaceaea)	Sannomiya et al. (2005)
Pectolinarigenin	Flavone	*Clerodendrum phlomidis*[a] (Verbenaceae)	Tripoli et al. (2007)

Adapted from Kumar and Pandey (2013)

[a]Scientific name of medicinal plants with their family names in brackets

15.2 Basic Structure

Dixon et al. (1983) in their studies reported flavonoids to be hydroxylated phenolic compounds produced by plants to fight against microbial infections. The structure of flavonoids decides the mechanism of action of the flavonoids, i.e., the action of flavonoids is the function of their structure. Their chemical nature is decided by a number of factors with the degree of polymerization and hydroxylation, structural class, other substitutions, and conjugations being the prominent ones among them. Flavonoids are essentially 2-phenyl-benzo-γ-pyrone derivatives that contribute to a major portion of the phenolic material in grapes and include several classes. The flavonoid molecules consist of oxygen-containing pyrene ring (C), coupled with two connecting benzene rings denoted as A and B (Fig. 15.1.). All the flavonoids are having a carbon skeleton based on the flavan system (C6-C3-C6) as a common part in their chemical structure (Teixeira et al. 2013).

Based on the number of sugar molecules linked, flavonoids are called as flavonoid glycoside if linked to one or more sugar molecules and aglycones if devoid of any linkages with the sugar molecule. Mostly flavonoids occur in plants and foods as glycosides except for flavan-3-ol. The complexity of flavonoids depends on their combination with sugars, kind of acylation, and a large number of other molecules (Beecher 2003). Chalcones, formed due to the condensation of A and B rings, undergo a process of cyclization involving isomerase and results in the formation of flavanone that is the working compound for the formation of other flavonoid groups.

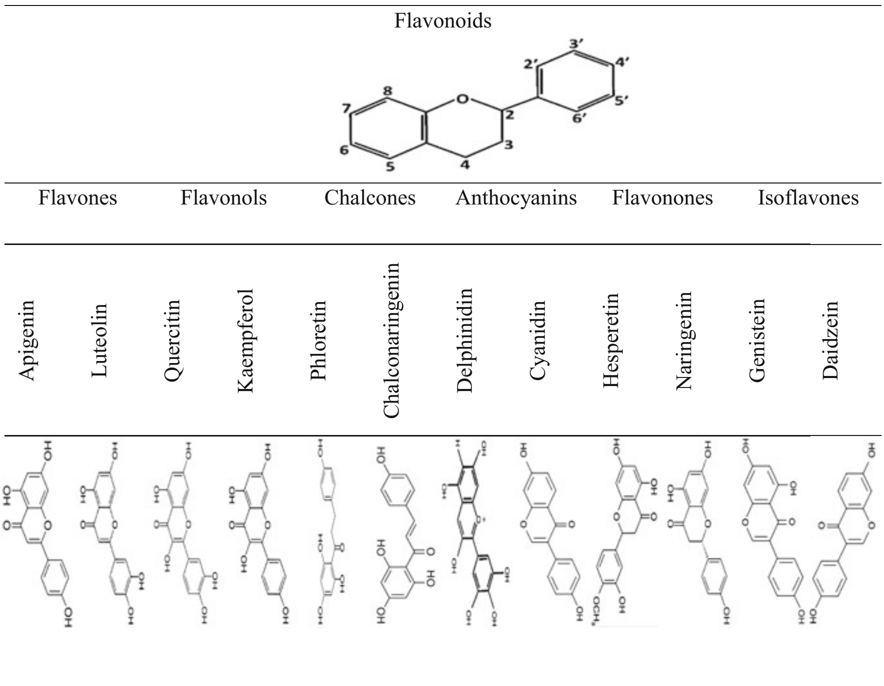


Fig. 15.1 The basic structure of flavonoids and their classes

15.3 Nomenclature of Flavonoids

Flavonoids are assigned names in three different manners. *Trivial* names of flavonoids indicate the plant source or flavonoid class, for example, "inidin" denoting "anthocyanidin," "etin" as "flavonol." Similarly, the compounds like tricin and hypolaetin denote that the compounds are extracted from plants of Triticum and Hypolaena genera. A *semi-systematic* manner based on trivial names such as flavone, chalcone as the parent structure. The third kind of nomenclature may be a *systematic* one in which flavonoids are recognized by their chemical names such as 3,4-dihydro-2-phenyl,2H-1-benzopyran for flavan. Out of the three, the last one is quite cumbersome and rarely used.

15.4 Recommended Dietary Allowance (RDA) of Flavonoids

It is very much difficult to estimate the dietary consumption of flavonoids due to various reasons (Scalbert and Williamson 2000). The prominent ones among them are the diversity in structure, wide distribution, and their content variability in different foods. Nevertheless, researchers have developed various methods for their estimation. The easy and the most commonly used methods are absolute and relative intake methods. In the absolute method, we calculate the amount of ingested flavonoids out of the total flavonoid content in the foods. While as in the relative method, the biomarkers of a relative flavonoid are referred. It can be justified by taking an example of two persons, among which the one having a genistein blood level twice than the other is assumed to have higher isoflavone intake than the other, considering blood genistein a good biomarker of isoflavone.

Normally, a human being consumes a flavonoid content of only 20–80 mg/day due to their destruction caused by acidity, boiling, and processing even if the fruits and vegetables may provide flavonoids as high as 300 mg/kg fresh weight. There is no fixed RDA for the flavonoids due to their diverse applications such as 500 mg flavonoids per day under the conditions of supplementation, 50–500 mg if therapeutic and health benefits to be furnished are recommended (Rucker 2004).

15.5 Sources of Flavonoids

Flavonoids are found ubiquitously in plants, which makes them an obligatory part of the human diet. Being ubiquitous in all plants, flavonoids have been reported to be present in a maximum concentration in fruits (Wang et al. 2018). The major sources of flavonoids include tea, onions, apples, and red wine as confirmed after analyses by the studies in The Netherlands. Moreover, studies have estimated the flavonoid's dietary intake range between 23 mg/day in The Netherlands and 170 mg/day estimated in the USA (Cook and Samman 1996). Flavonoids are also present in the citrus fruit peels and residues after juice extraction. However, flavonoids were characterized in terms of the flavonoid constituents (naringin and hesperidin), and polymethoxyflavones (PMFs) in Thai citrus residues (Chinapongtitiwat et al. 2013). Their studies found Naringin to be the dominant flavanone in pomelo peels. Mandal et al. (2010) reported the wide application of Hygrophila spinosa, a flavonoid-rich herb coupled with alkaloids, tannins, and essential oils in the treatment of diseases such as jaundice, renal disorders, and hepatic dysfunction in India.

Polyphenols vary largely in food and plant products as shown in Table 15.2. Among the main sources, fruits and beverages like tea and red wine are the prominent ones. Most of the foods constitute complex polyphenol mixtures due to which their properties are hard to explore. Polyphenols may be either food specific such as flavanones present in citrus fruit, isoflavones in soy, phloridzin in apples or present in all kinds of plant products such as quercetin in fruits, vegetables, cereals, leguminous plants, fruit juices, tea, wine, and infusions (Manach et al. 2004). Studies have shown even if the polyphenol profile among all the apple varieties is almost similar yet, their concentration varies from 0.1 to 5 g total polyphenols/kg fresh weight (wt.) and could be as high as 10 g/kg in certain varieties of cider apples (Sanoner et al. 1999). A number of foods such as certain fruit and cereal types are to be explored practically for the polyphenol profiles. Besides, certain other factors like ripeness at the time of harvest, environmental factors, processing, and storage also determine the polyphenol profiles of the foods (Manach et al. 2004).

15.6 Classification of Flavonoids

Based on the factors such as nature of carbon of the C ring on which the B ring is attached, the degree of unsaturation and oxidation of the C ring, flavonoids are divided into subclasses such as isoflavones, having B ring linked at position 3, neoflavonoids with B ring attached at position 4 of the C ring. Flavonoids with B ring attached at position 2 are further divided into classes such as flavones, flavonols, flavanones, flavanonols, flavanols or catechins, anthocyanins, and chalcones based on the C ring structure (Panche and Diwan 2016) (Fig. 15.1).

15.6.1 Flavones

Flavones such as luteolin, apigenin, and tangeritinare reported to be mostly present in celery, parsley, red peppers, chamomile, mint, and *Ginkgo biloba* leaves, flowers, and fruits in glycoside form (Fig. 15.1). These are characterized by a ketone at carbon 4 and a double bond between carbon number 2 and 3 of the C ring. Manach et al. (2004) reported the abundance of polymethoxylated flavones, tangeretin, nobiletin, and sinensetin constituting the citrus fruit peels. Among most of the fruits and vegetables, position 5 is seldom occupied by a hydroxyl group, while the hydroxyl groups are mostly present at position 7 of ring A or at 3′ and 4′ of the B ring, subject to the type of vegetables or fruits. Coupled with flavonols, flavones perform various functions in plants such as they act as co-pigments with anthocyanins in blue flowers (Harborne and Williams 2000). Flavones also absorb

Table 15.2 Flavonoid content in major food sources

Flavonoid type	Source (sample size)	Flavonoid content mg/kg fresh wt (or mg/L)	References
Anthocyanins Cyanidin Pelargonidin Peonidin Delphinidin	Aubergine (200 g) Blackberry (100 g) Black currant (100 g) Blueberry (100 g) Black grape (200 g) Cherry (200 g) Rhubarb (100 g) Strawberry (200 g) Red wine (100 mL) Plum (200 g) Red cabbage (200 g)	7500 1000–4000 1300–4000 250–5000 300–7500 350–4500 2000 150–750 200–350 20–250 250	Clifford (2000), Mazza and Miniati 2018
Flavonols Quercetin Kaempferol Myricetin	Yellow onion (100 g) Curly kale (200 g) Leek (200 g) Cherry tomato (200 g) Broccoli (200 g) Blueberry (100 g) Black currant (100 g) Apricot (200 g) Apple (200 g) Beans, green/white (200 g) Black grape (200 g) Tomato (200 g) Black tea infusion (200 mL) Green tea infusion (200 mL) Red wine (100 mL)	350–1200 300–600 30–225 15–200 40–100 30–160 30–70 25–50 20–40 10–50 15–40 2–15 30–45 20–35 2–30	Justesen et al. (1998), Price and Rhodes (1997), Hollman and Arts (2000), Crozier et al. (1997)
Flavones Apigenin Luteolin	Parsley (5 g) Celery (200 g) Capsicum pepper (100 g)	240–1850 20–140 5–10	Hertog et al. (1992), Justesen et al. (1998), Crozier et al. (1997)
Flavanones Hesperidin Naringenin Eriodictyol	Orange juice (200 mL) Grapefruit juice (200 mL) Lemon juice (200 mL)	215–685 100–650 50–300	(Mouly et al. 1994), (Tomás-Barberán and Clifford 2000)
Isoflavones Daidzein Genistein Glycitein	Soy flour (75 g) Soybeans, boiled (200 g) Miso (100 g) Tofu (100 g) 80–700 8–70 Tempeh (100 g) Soy milk (200 mL)	800–1800 200–900 250–900 80–700 430–530 30–175	Franke et al. (1999), Cassidy et al. (2000)
Monomeric flavanols Catechin Epicatechin	Chocolate (50 mg) Beans (200 g) Apricot (200 mg) Cherry (200 g) Grape (200 g) Peach (200 g)	460–610 350–550 100–250 50–220 30–175 50–140	Hollman and Arts (2000), de Pascual-Teresa et al. (2000), Arts et al. (2000)

(continued)

Table 15.2 (continued)

Flavonoid type	Source (sample size)	Flavonoid content mg/kg fresh wt (or mg/L)	References
	Blackberry (100 g) Apple (200 g) Green tea (200 mL) Black tea (200 mL) Red wine (100 mL) Cider (200 mL)	130 20–120 100–800 60–500 80–300 40	

Adapted from Manach et al. (2004)

UVB in the 280–315 nm range thereby protecting the plants from their detrimental effects and form a constituent of primary pigments in white and cream-colored flowers coupled with the in-built defensive nature against pesticides and insects in plants (Harborne 2017).

Flavones are non-toxic and overloaded with so many previously mentioned health benefits, which leads to their obligatory incorporation in food systems, and thus their daily intake in our diet becomes of great concern. Various researchers after surveying have reported the daily intake of flavonoids such as Pounis et al. (2016) reported the daily intake range of flavonoids in adults in Europe between 0.7 and 9.0 mg/day of which flavones form the major constituent. The same range was reported in women in the USA between 1.1–1.6 mg/day (Wang et al. 2014) and 1.9–4.2 mg/day in female adolescents in China (Sun et al. 2015).

A survey on the juices based on the total flavone content enlisted bergamot juice at the top position with the highest concentration of total flavone glycosides, including both flavone O- and C-glycosides.

Among the fresh foods, parsley was reported to be the number one contender with the highest concentration (1484 mg apigenin/100 g) of flavone (Mattila et al. 2000). Similarly, millet and sorghum among the cereals and legumes and sunflower family (Asteraceae) and carrot family (Apiaceae) among the vegetables have the highest flavone concentrations.

15.6.2 Flavonols

Flavonols are the basic building blocks of proanthocyanins with ketone containing a group. A hydroxyl group is attached to position 3 of the C ring, which may also be glycosylated. Flavonols represent the ubiquitous class among the flavonoids in foods, of which quercetin and kaempferol are the main representatives. Some of the rich sources of flavonols are onions, tomatoes, apples, grapes, kale, etc. Besides fruits and vegetables, tea and red wine also represent important sources of flavonols (Crozier et al. 1997). The health benefits such as antioxidant potential and reduced risk of vascular disease determine the flavonol intake. The total intake and content of flavonoids in foods are quite higher than reported because the reported ones are mostly based on two components, i.e., flavonols (quercetin, myricetin, and kaempferol) and flavones (apigenin and luteolin). The highest content of flavonols is predominantly present in skins and leaves of fruits and vegetables. Moreover, the method of cooking affects the flavonol retention in foods such as quercetin content is greatly reduced by boiling the food (Ewald et al. 1999).

In processed foods, flavonol content is reduced nearly to half as compared to the fresh products (Price and Rhodes 1997). The extraction step in the juice processing results in the liberation of flavonoids from the rind of the fruit, thereby increasing the flavonoid content (Van Der Sluis et al. 1997). Moreover, the processed wine has comparatively a higher quercetin concentration than the fresh fruits like grapes and berries, which could be credited to the application of modern processing methods of vinification (McDonald et al. 1998).

15.6.3 Flavanones

Flavanones constituting hesperetin, naringenin, and eriodictyol are another important class of flavonoids that are considered as the characteristic constituents of citrus fruit. The bitter taste of the juice and peel of citrus fruits is due to flavanones. Flavanones are present in both tissues and juices of the citrus fruits, but the solid tissue reserves the higher concentration. For example, a concentration of 295 ± 377 mg L^{-1} naringin was reported from grape fruit juice which was only 13–16, 18–27, and 11.5–17.6 g kg^{-1} from the albedo, back membrane, and side membrane of the same fruit, respectively (McIntosh and Mansell 1997).

Flavanones are also called as dihydroflavones (Iwashina 2013). Flavanones are much easily separated in fractional crystallization if present in chilled or frozen solution, precipitated at low pH and are less soluble than chalcones. Moreover, flavanones are converted to their corresponding isomeric chalcones in alkaline media (or vice versa in acidic media) if the flavanone constitutes a hydroxyl substituent at position 2′ (or 6′) (Tomás-Barberán and Clifford 2000). Flavanones occur in various forms of glycosides such as rutinosides (6-*O*-α-L-rhamnosyl-D-glucosides) and neohesperidosides (2-*O*-α-L-rhamnosyl-D-glucosides) normally attached at position 7. Among the health benefits, free radical scavenging properties are quite remarkable. In addition to the hydroxylation of naringenin 7-glucoside, gut microflora of human intestines absorb the flavanone aglycones which are then excreted as glucuronides but are unable to absorb flavanone neohesperidosides and rutinosides. Moreover, no evidence of absorption of the corresponding glucosides in duodenum has yet been reported (Day et al. 1998).

15.6.4 Isoflavonoids

Isoflavonoids are a large and very distinctive subgroup of flavonoids, generally found in Papilionoideae, a subfamily of the Leguminosae family. Unlike flavonoids, isoflavonoids are having a 3-phenylchroman skeleton that is biogenetically derived from the 2-phenylchroman skeleton of the flavonoids (Harborne 1989). Isoflavonoids are also found in microbes (Matthies et al. 2008) and also act as precursors for the development of phytoalexins during plant–microbe interactions.

Like flavonoids, isoflavonoids are also present in foods predominantly as glycosidic conjugates with higher water solubility than the parent aglycones and require mammalian or microbial glycosidase enzymes for the sugar breakdown prior to absorption. Isoflavonoids are linked to the treatment of a number of diseases. For example, genistein and daidzein are found to be phyto-estrogenic in nature reported in certain animal models. Moreover, isoflavonoids are found to influence pathways of a number of diseases credited to genistein resulting in hormonal and metabolic changes (Szkudelska and Nogowski 2007). Isoflavonoids are also associated with cancer prevention supported by a study demonstrating the role of soybean flavonoids in reducing the cancer rates. However, soybean is also a good source of trypsin inhibitor and proteins with a lot of health benefits.

15.6.5 Flavanols

Flavanols are the derivatives of flavanones. In flavanols, the hydroxyl group is bound to position 3 of the C ring that gives them the name flavan-3-ol. Both monomeric form (catechins) and the polymeric form (proanthocyanidins) of flavanols are known (Panche and Diwan 2016) as shown in Fig. 15.1. Fruits are the main sources of flavanols mostly found in a higher concentration in bananas, apples, blueberries, peaches, and pears. Among the fruits, apricots with 250 mg/kg fresh weight represent the richest source of catechins as depicted from Table 15.2 (Manach et al. 2004). The representative flavanols in fruits are catechin and epicatechin whereas the same in seeds of leguminous plants are gallocatechin, epigallocatechin, and epigallocatechin gallate. Despite being the highly diversified and multi-substituted subgroup, flavanols are the only class in flavonoids not glycosylated in foods. Catechins cause inhibition of tumor progression by reduction of recurrence I and II stages coupled with the decrease in a number of axillary lymph node metastases in breast cancer. This has been reported after prolonged consumption of green tea by Japanese patients. During fermentation or heating process, such as in the case of black tea, monomer flavanols are converted to the aflavins and the arubigins, which are dimers and polymers, respectively.

15.6.6 Anthocyanins

The word Anthocyanin comes from the Greek word "Anthos" meaning "flower" and "kianos" meaning "blue." They are widely distributed among flowers, fruits (particularly in berries), and vegetables and are responsible for the bright colors such as orange, red, and blue. Some of the common types of anthocyanins are cyanidin, delphinidin, malvidin, pelargonidin, and peonidin. They play a vital role in the mechanism of plant resistance to insect attack. In addition, anthocyanins furnish colors to the plants (Harborne 2017) and attract a number of animals thereby assist in pollination and seed dispersal.

Chemically, anthocyanins are glycoside and acylglycoside derivatives of anthocyanidins with their basic structure represented in Fig. 15.1. All of the 250 naturally occurring anthocyanins reported are *O*-glycosylated with different sugar substitutes such as glucose, rhamnose, xylose, galactose, arabinose, and fructose (Francis and Markakis 2009). The common anthocyanins are either 3- or 3,5-glycosylated. Compared to carotenoids, anthocyanins are less stable coupled with a higher water solubility and grapes, berries, red cabbage, apples, radishes, tulips, roses, and orchids are the main sources from which they are extracted. The isolated anthocyanins are prone to degradation due to instability depending on a number of factors such as pH, storage temperature, chemical structure, concentration, light, oxygen, solvents, the presence of enzymes, flavonoids, proteins, and metallic ions (Rein 2005). Anthocyanins foil the harmful effects on proteins, nucleic acids, and lipids by scavenging the free radicals and thereby preventing the plant cell constituents against oxidative damage (Rice-Evans et al. 1996). Degenerative diseases like cancer and cardiovascular disease are treated actively by anthocyanins due to their antioxidant activity (Lambert et al. 2005). Moreover, they play a vital role in preventing neuronal diseases. Giusti and Wrolstad (2003) reported that anthocyanins are used as food colorants and endow stability to commercial food products.

Anthocyanin color is determined by the degree of methylation or acylation to the hydroxyl groups on the A and B rings and the pH. Netzel et al. (2007) reported the health benefits of anthocyanin from black carrot in retarding the human cancer cells growth in vitro. Anthocyanins are found in fruits such as cranberries, black currants, red grapes, merlot grapes, raspberries, strawberries, blueberries, bilberries, and blackberries chiefly in their outer cell layers.

15.6.7 Chalcones

Chalcones, also called as α-β-unsaturated ketones are the key structural motif among the biologically active molecules, distributed widely in fruits, vegetables, spices, tea, and soy-based foodstuffs. Chalconesor 1,3-diaryl-2-propen-1-ones are a subclass of flavonoids characterized by the absence of "ring C" of the basic flavonoid skeleton structure as shown in Fig. 15.1. Hence, they can also be referred to as open-chain flavonoids, for example, phloridzin, arbutin, phloretin, and chalconaringenin. The main sources of chalcones are tomatoes, pears, strawberries, bearberries, and certain wheat products.

There has been a great concern shown by researchers on this flavonoid class due to their pharmacological properties. Among the pharmacological and medicinal aspects of chalcones, the prominent ones are anticancerous, antimicrobial, antibacterial, cytotoxic, anti-inflammatory, anti-HIV, antitumor antifungal, and antioxidant (Go et al. 2012). They form a major constituent in natural products. The biological activity of chalcones is due to the presence of a double bond in conjugation with carbonyl functionality (Singh et al. 2014). In China, Fenwick et al. (1990) reported the effective treatment of diseases such as bronchial asthma, gastric and duodenal ulcers, Addison's disease, food, and drug poisoning and skin disease such as eczema and urticaria with the help of liquorice, a chalcone. Moreover, liquorice has been reported as an important ingredient for industries such as tobacco, confectionery, and pharmaceutical (Nowakowska 2007). Tsukiyama et al. (2002) witnessed the trending bacteriostatic effects of licochalcone on Gram-positive bacteria.

15.7 Biosynthesis of Flavonoids

It was 1664 when Robert Boyle claimed the discovery of flavonoids and as components of plant pigments. Nowadays, a lot of research has been reported on these secondary metabolites related to their structural characterization and biosynthesis. Also, their role with beneficial effects on health was revealed (Winkel-Shirley 2001).

The synthesis of flavonoids occurs through the phenylpropanoid pathway in which phenylalanine enters into the flavonoid biosynthesis pathway with an intermediate step of conversion of phenylalanine into 4-coumaroylCoA. Chalcone scaffolds are the first intermediate products in this pathway from which all the flavonoids are derived with the help of an enzyme "chalcone synthase." Martens et al. (2010) reported enzymes such as isomerases, reductases, hydroxylases, and several Fe^{2+}/2-oxoglutarate-dependent dioxygenases help to derive the basic flavonoid structure which further gives rise to different subclasses. Finally, there is a modification of the basic structure of flavonoids with sugars, methyl groups, and/or acyl moieties and fluctuating their solubility, reactivity, and interaction with cellular targets. This transformation is completed by a transferase enzyme.

15.8 Functional Aspects of Flavonoids

The definition of the term "functional food" is now and then changed according to various regulatory bodies. In order to call food to be a functional food, besides providing basic nutrition it should also furnish health benefits (Hasler et al. 2004). As the fruits and vegetables represent the simplest form of functional foods and are the rich stores of various bioactive phytochemicals including flavonoids with strong antioxidant activity. As reports of the presence of almost 5000 distinct flavonoids in plants are there and almost hundreds among them present in the foods consumed on a daily basis. Hence, flavonoids may also be categorized as a functional food or a part of it. Some of the functional aspects of flavonoids are discussed:

15.8.1 Antimicrobial Activity of Flavonoids

Currently, studies revealed that among the two million cases registered in the USA, 70% of cases consist of strains resistant to at least one drug. This resistance to antimicrobial agents has become a serious global problem that needs to be addressed. Hence, this field has sought ample attention from the researchers. Studies have shown that flavonoids have become one of the trending subjects in anti-infective research, and flavonoids are potent antifungal, antiviral, and antibacterial agents. For example, the high flavonoid content of propolis (bee glue) is found to be credited for the antimicrobial activity against various bacteria particularly the human tubercle bacillus (Grange and Davey 1990).

Since long, researchers have reported flavonoids to be used by a number of physicians and lay healers for treating human diseases for the reason of being the principal physiologically active constituents (Havsteen 1983). A flavonoid called quercetagetin-7-arabinosyl-galactoside from *Tagetes minuta* plant has proved its antimicrobial effects against some of the infectious diseases (Bosio et al. 2000). Similarly, some research groups have reported antimicrobial and healing properties of propolis that is attributed in particular to flavonoids such as galangin and pinocembrin (Hegazi et al. 2000). Moreover, baicalein, a flavone is found to have preventive nature against periodontal abscesses and infected oral wounds which is actually responsible for the antimicrobial effects of that plant and is used since long in China (Tsao et al. 1982).

15.8.2 Antioxidant Activity of Flavonoids

The degradation of protein, lipid, sugar, DNA, RNA, etc. is prevented by the antioxidant properties of flavonoids, which makes the flavonoids quite beneficial. Moreover, flavonoids are having chelating properties. Flavonoids prevent the free radicals from forming the reactive oxygen species (ROS), superoxide anion, hydroxyl, and peroxyl radicals, which could otherwise damage these biomolecules by their attack on deoxyribose and nitrogen bases (Aron and Kennedy 2008). The study on antioxidant activity determined by various methods such as 1-1′-diphenyl 2-picrylhydrazyl (DPPH), *N,N*-dimethyl-p-phenylenediamine (DMPD) reported flavonoids as better antioxidant alternatives in meat and meat products.

The mechanism of antioxidant activity of flavonoids is based on the free radical scavenging power, which in turn depends on hydrogen donating capacity. The antioxidant activity of flavonoids also depends on the number and the position of highly reactive hydroxyl groups attached to the ring B. For example, the flavonoids with hydroxyl groups at position 3 are ten times more antioxidant effective. Moreover, their antioxidant activity is increased by the double bond between carbon 2 and 3. Under oxidative stress and lipid peroxidation, these prove to be persuasive candidates in inhibiting the enzymes such as xanthine oxidase, lipoxygenase, and cyclo-oxygenase and NADH oxidase is responsible for the production of free radicals. The order of antioxidant activity among the flavonoids is as flavanols>flavonols>chalcones> flavones >isoflavones, except the quercetin (Cai et al. 2006).

15.8.3 Preventive and Health Benefits of Flavonoids

Recently, there is been a transferal from synthetic antioxidants such as BHA, and BHT which are alleged to be carcinogenic (Branen 1975) towards the development of natural antioxidants from plant material in food industry and medicine. The high contents of isoflavone in soy defines the anticancer effects of soy-based foods. Green tea has preventive action on cardiovascular and cerebrovascular diseases in addition to antitumor, antioxidant, antigenotoxic and anticaries activities. In countering the detrimental effect of cells due to cancer, heart disease, and other illness, green tea is reported to be 100 times and 25 times more potent than vitamin C and vitamin E, respectively.

Flavonoids are the compounds extracted from several plant parts. Flavonoids are believed to have numerous astounding health benefits coupled with the property of modulation of key cellular functions besides improving plant health and protection such as fixing nitrogen, attracting insects that help in pollination, cell cycle inhibition, and UV filtration (Kamboh et al. 2019). Among the health benefits of flavonoids in animals, immune modulation, antioxidation, and anti-allergy is worth mentioning. Moreover, in TGFβ-pathway, they inhibit the binding of ATP by tyrosine kinases. Isoflavonoids are also called as "phytoestrogens" due to their estrogenic/anti-estrogenic activity after they bind to estrogen-receptors (Adlercreutz and Mazur 1997). They also help in the induction of cell cycle arrest in various kinds of tumors such as Genistein and Quercetin induce apoptosis by inhibiting tyrosine protein kinases and DNA topoisomerase II. Hence, also known as anti-tumorigenic agents (Traganos et al. 1992). Studies have unveiled the medicinal use of flavonoids in maintaining healthy capillary and blood vessel functions for long (Strissel and Strick 2005). Recent studies exposed that citrus fruits like *Citrus bergamia*, *Risso* and *Poiteau*, commonly known as *bergamot* to be having the anticancer, antimicrobial, antioxidant, and anti-inflammatory activities (Celia et al. 2013; Risitano et al. 2014). Visalli et al. (2014) reported the consideration of flavonoid fraction extracted from the bergamot as a potent inhibitor of cancer cell proliferation.

Nowadays, flavonoids are considered as potent cancer negotiators due to their extraordinary chemically reactive nature particularly through the induction of apoptosis (Moyers and Kumar 2004). For example, Ingram et al. (1997) reported the reduction of breast cancer by Genistein from soy. Furthermore, studies showed the deceleration of signal transduction in breast tumor cells synergistically in combination with Tamoxifen (Shen et al. 1999). Nevertheless, Catechins also reduced the recurrence of stage I and II in breast cancer thereby inhibiting the tumor progression.

Not confined to mere native bioflavonoids, researchers also explored the cancer applications of bioflavonoids that are being modified chemically. Flavopiridol, a semi-synthetic bioflavonoid caused the induction of apoptosis resulting in tumor regression due to their inherent property of DNA intercalation and inhibition of

Table 15.3 Various phytochemicals with their sources and health benefits

Food sources	Constituent phytochemical	Human health benefits
Apples, berries, cherries, citrus fruits, prunes, plums, whole grains, and nuts	Flavonoids	Cancer prevention and increase in HDL cholesterol
Grapes (red and muscadines), red wine, and peanuts	Stilbenes (resveratrol)	Diminish the heart disease and risk of certain cancers
Green and black tea	Catechins	Reduce the risk of heart disease, stroke, and certain cancers
Onions, garlic, chives, and leeks	Allyl sulfides	Reduce the risk of heart disease and certain cancers also may lower LDL cholesterol
Tomatoes, sweet potatoes, and spinach (Deeply colored fruits and vegetables)	Carotenoids (lutein, beta-carotene, and lycopene)	Protect eyes (macular degeneration), prevent certain cancers (prostate), and help in strengthening the immune system
Broccoli, cauliflower, cabbage, turnips, and Brussels sprouts	Indoles	Breast and colon cancer prevention
Broccoli, Brussels sprouts c, cabbage, turnips, and cauliflower	Isothiocyanates	May disarm cancer-causing materials
Oranges, grapefruits, tangerines, lemon, and lime (citrus fruits and juices)	Monoterpenes	May inactivate cancer-causing materials
Tofu, soy milk, soy nuts (soy foods) and kidney beans, northern beans, and chickpeas (legumes)	Isoflavones	May lower LDL cholesterol and protect against breast, ovarian, colon, and prostate cancer
Potatoes, green vegetables, tomatoes, nuts, soy foods, and legumes	Saponins	May provide protection against cancer
Oats	β-glucan	May lower total and LDL cholesterol and prevent cardiovascular disease

Adapted from Boue et al. (2009)

cyclin-dependent kinases and transcription (Senderowicz 2003). Also, flavonoids act as inhibitors of several enzymes such as xanthine oxidase (XO), cyclo-oxygenase (COX), lipoxygenase, and phosphoinositide 3-kinase (Table 15.3).

15.9 Metabolism and Bioavailability of Flavonoids

Polyphenols including flavonoids occur most commonly in the human diet. Because of the reasons for the lower intrinsic activity or poorly absorbed from the intestine highly metabolized, or rapidly eliminated flavonoids are not necessarily the most active within the body (Manach et al. 2004). Owing to their antioxidant properties, preventive roles in diseases associated with oxidative stress, such as cancer and cardiovascular and neurodegenerative diseases, researchers, and food manufacturers are keenly interested in polyphenols like flavonoids over the past decade. In the human body, intestinal and hepatic enzymes along with intestinal microflora help to metabolize these flavonoids. Nonetheless, it is quite evident that not all flavonoids are absorbed with the same efficacy and stride. So their bioavailability and metabolism within the target tissues, henceforth evaluating their biological activity is of great concern (Manach et al. 2004).

Bioavailability can be defined as "the rate and extent to which an ingredient is absorbed and becomes available to the site of action." According to another definition, bioavailability means that a fraction of the consumed ingredient, which appears in the bloodstream. The stepwise processes starting from digestion and liberation in the stomach and the gastrointestinal tract, incorporation into the bloodstream through the membrane, distribution among the tissues, their metabolism and effects, and finally ending with their elimination collectively involve the whole process of bioavailability and bio-efficacy. Flavonoids are mostly absorbed and finally excreted. No long-term stores in our body are claimed, yet some reports of biological effects of flavonoids in some tissues at measurable concentrations are there (Hong et al. 2001). Among the various bioavailability determining methods such as the postprandial test, the oral-intravenous balance, the oral-fecal balance, and observation of the effects of chronic consumption, the postprandial test is the most commonly used method. Polyphenols including flavonoid digestion and then absorption start right from the stomach and is a function of various factors such as dose, dietary fat intake, the form ingested, gut transit time, and fecal degradation rate (Lesser et al. 2004).

The stomach is the site for most of the aglycones of polyphenols except anthocyanins which are reported to remain intact in the stomach. All the polyphenols including flavonoids follow the same pathway of metabolism (Scalbert and Williamson 2000). The first stage in the process of metabolism of flavonoids is the deglycosylation of flavonoid glycosides. The liver is considered the chief organ for flavonoid metabolism in addition to the intestinal mucosa and/or kidneys to some extent. The drug-metabolizing enzymes present in intestinal epithelium are responsible for the metabolism of flavonoids as almost all of them reach the small intestines intact. Finally, flavonoids are supplied to the liver through the portal vein by binding with albumin after absorption. In the small intestines, some of the complexes such as methylated, glucuronidated, or sulfated metabolites are formed after the absorption of flavonoid aglycones and flavonoid glucosides (Kay 2005). Bacterial enzymes present in the colon further metabolize the flavonoid metabolites and cause their absorption. Among the polyphenols, isoflavones, followed by quercetin glucosides (flavonol) are absorbed in humans up to a large extent, while as Proanthocyanidins and the flavan-3-ol epigallocatechin gallate (EGCG) are least absorbed which could be due to the reason of instability, not the poor absorption (Manach et al. 2005).

Among the flavonoids, flavonols, flavanones, isoflavones, and flavan-3-ols exert biological effects after being absorbed sufficiently in conjugated forms (Williamson et al. 2005). Out of the two pathways viz., urinary and biliary excretion, through which the polyphenol metabolites are lost from the human body, biliary excretion is an important one. The other, i.e., urinary excretion is regarded as an important pathway for the flavonoids such as flavanones, isoflavones, and flavan-3-ols.

15.10 Development of Functional Foods by the Incorporation of Flavonoids

From the last decade or so, functional foods have become a developing area of interest in the field of food science that has created an inclination among the researchers towards them. This approach has resulted in the development of various plant-based foods containing natural compounds effective against certain diseases coupled with human health advantages. In the 1980s, there was a big revolution in the name of functional foods (foods with health benefits) in Japan. Later in 1991, Food for Specified Health Use (FOSHU) concept came according to which it was revealed that human health is very much affected by the food constituents. This concept brought awareness among the consumers, which compelled the industries and food researchers to think of a new world of developing healthy foods having positive health benefits (Lanjewar et al. 2009).

The high-quality proteins, fats, minerals, and vitamins in meat makes it a healthy and nutritive nutritious source (Naga Mallika et al. 2009), but at the same time prone to perishability due to the absence of inherent antioxidants. Flavonoids prove to be the potent antioxidants to cater to the aforesaid problem of perishability. Moreover, the binding, therapeutic as well as functional value of meat and meat products is increased (Ruban et al. 2009).

Zainol et al. (2009) in their study on *Centella asiatica* leaf found quercetin to be the most degraded flavonoid with catechin and rutin least affected by different drying methods like freeze-drying, vacuum oven, and air oven. The development of cocoa powder after the supplementation of procyanidins is very helpful in curing cardiovascular diseases coupled with other health benefits (Keen et al. 2005). In another study, cocoa milk powder incorporated with eight times more epicatechin and procyanidin, proved helpful for cardiovascular diseases. Flavonoid enriched foods such as flavanol-rich cocoa are also helpful in improving the function of endothelium which is actually due to the presence of procyanidin-derived metabolites in plasma (Schroeter et al. 2006).

15.11 Conclusion

Dietary flavonoids represent an important source of antioxidants that exhibit multifarious effects in the protection of the human body. Moreover, flavonoids are having wide applications in food industries because of the trendy health-conscious consumer behavior and the toxic effects of synthetic antioxidants. Flavonoids present an in vitro health benefits contrary to synthetic antioxidants, antioxidant activity in both aglycon and the glycoside-absorbed forms coupled with the improvement in the functioning of the endothelium. According to current knowledge, a diet that includes flavonoid-containing products should be promoted. However, the side effects of the flavonoids when consumed in large doses presents lacunae that needs to be explored and hence, the use of their dietary supplements should be analyzed with utmost concern.

References

Aderogba MA, Ogundaini AO, Eloff JN (2006) Isolation of two flavonoids from Bauhinia monandra (Kurz) leaves and their antioxidative effects. Afr J Tradit Complement Altern Med 3:59–65

Adlercreutz H, Mazur W (1997) Phyto-oestrogens and Western diseases. Ann Med 29:95–120

Agarwal M, Kamal R (2007) Studies on flavonoid production using in vitro cultures of Momordica charantia L. Indian J Biotechnol 6:277–279

Aron PM, Kennedy JA (2008) Flavan-3-ols: nature, occurrence and biological activity. Mol Nutr Food Res 52:79–104

Arts ICW, Van De Putte B, Hollman PCH (2000) Catechin contents of foods commonly consumed in The Netherlands. 1. Fruits, vegetables, staple foods, and processed foods. J Agric Food Chem 48:1746–1751

Avula M, Pallu R, Reddy GV (2010) Anti inflammatory activity of flavonoid fraction isolated from the stem bark of Butea monosperma (Lam): a mechanism based study. Int J Phytopharmacol 1:124–132

Beecher GR (2003) Overview of Dietary Flavonoids: nomenclature, Occurrence and Intake. J Nutr 133:3248S–3254S

Bentsáth A, Rusznyák S, Szent-Györgyi A (1936) Vitamin nature of flavones. Nature 138:798

Bosio K, Avanzini C, D'Avolio A, Ozino O, Savoia D (2000) In vitro activity of propolis against Streptococcus pyogenes. Lett Appl Microbiol 31:174–177

Boue SM, Cleveland TE, Carter-Wientjes C, Shih BY, Bhatnagar D, McLachlan JM, Burow ME (2009) Phytoalexin-enriched functional foods. J Agric Food Chem 57:2614–2622

Branen AL (1975) Toxicology and biochemistry of butylated hydroxyanisole and butylated hydroxytoluene. J Am Oil Chem Soc 52:59

Cook NC, Samman S (1996) Flavonoids—chemistry, metabolism, cardioprotective effects, and dietary sources. J Nutr Biochem 7:66–76

Cai YZ, Sun M, Xing J, Luo Q, Corke H (2006) Structure-radical scavenging activity relationships of phenolic compounds from traditional Chinese medicinal plants. Life Sci 78:2872–2888

Cassidy A, Hanley B, Lamuela-Raventos RM (2000) Isoflavones, lignans and stilbenes—origins, metabolism and potential importance to human health. J Sci Food Agric 80:1044–1062

Castañeda-ovando A, Pacheco-hernández MDL, Páez-hernández ME, Rodríguez JA, Galán-vidal CA (2009) Chemical studies of anthocyanins: a review. Food Chem 113:859–871

Celia C, Trapasso E, Locatelli M, Navarra M, Ventura CA, Wolfram J, Paolino D (2013) Anticancer activity of liposomal bergamot essential oil (BEO) on human neuroblastoma cells. Colloids Surf B Biointerfaces 112:548–553

Chinapongtitiwat V, Jongaroontaprangsee S, Chiewchan N, Devahastin S (2013) Important flavonoids and limonin in selected Thai citrus residues. J Funct Foods 5:1151–1158

Clifford MN (2000) Anthocyanins—nature, occurrence and dietary burden. J Sci Food Agric 80:1063–1072

Crozier A, Lean MEJ, McDonald MS, Black C (1997) Quantitative analysis of the flavonoid content of commercial tomatoes, onions, lettuce, and celery. J Agric Food Chem 45:590–595

Day AJ, Dupont MS, Ridle S, Rhodes M, Rhodes MJ, Morgan MR, Williamson G (1998) Deglycosylation of flavonoid and isoflavonoid glycosides by human small intestine and liver β-glucosidase activity. FEBS Lett 436:71–75

De Moraes Barros HR, De Castro Ferreira TAP, Genovese MI (2012) Antioxidant capacity and mineral content of pulp and peel from commercial cultivars of citrus from Brazil. Food Chem 134:1892–1898
de Pascual-Teresa S, Santos-Buelga C, Rivas-Gonzalo JG (2000) Quantitative analysis of flavan-3-ols in Spanish foodstuffs and beverages. J Agric Food Chem 48:5331–5337
Dewick PM (2009) The shikimate pathway: aromatic amino acids and phenylpropanoids. In: Medicinal natural products: a biosynthetic approach. Wiley, Chichester, pp 137–186
Dixon RA, Dey PM, Lamb CJ (1983) Phytoalexins: enzymology and molecular biology. Adv Enzymol Relat Areas Mol Biol 55:69
Ewald C, Fjelkner-Modig S, Johansson K, Sjöholm I, Åkesson B (1999) Effect of processing on major flavonoids in processed onions, green beans, and peas. Food Chem 64:231–235
Fenwick GR, Lutomski J, Nieman C (1990) Liquorice, Glycyrrhiza glabra L.—composition, uses and analysis. Food Chem 38:119–143
Francis FJ, Markakis PC (2009) Critical reviews in food science and nutrition food colorants: anthocyanins. Food Sci Nutr 28:273–314
Franke AA, Hankin JH, Yu MC, Maskarinec G, Low SH, Custer LJ (1999) Isoflavone levels in soy foods consumed by multiethnic populations in Singapore and Hawaii. J Agric Food Chem 47:977–986
Ghoulami S, Il Idrissi A, Fkih-Tetouani S (2001) Phytochemical study of Mentha longifolia of Morocco. Fitoterapia 72:596–598
Giusti MM, Wrolstad RE (2003) Acylated anthocyanins from edible sources and their applications in food systems. Biochem Eng J 14:217–225
Go M, Wu X, Liu X (2012) Chalcones: an update on cytotoxic and chemoprotective properties. Curr Med Chem 12:483–499
Grange JM, Davey RW (1990) Antibacterial properties of propolis (bee glue). J R Soc Med 83:159–160
Gupta KK, Taneja SC, Dhar KL, Atal CK (1983) Flavonoids of Andrographis paniculata. Phytochemistry 22:314–315
Harborne JB (2017) The flavonoids: advances in research since 1986. CRC, Boca Raton
Harborne JB (1989) General procedures and measurement of total phenolics. In: Dey PM, Harborne JB (eds) Methods in plant biochemistry. Plant phenolics. Academic, London, pp 1–28
Harborne JB, Williams CA (2000) Advances in flavonoid research since 1992. Phytochemistry 55:481–504
Hasler CM, Bloch AS, Thomson CA (2004) Position of the American Dietetic Association: functional foods. J Am Diet Assoc 104:814–826
Havsteen B (1983) Flavonoids, a class of natural products of high pharmacological potency. Biochem Pharmacol 32:1141–1148
Havsteen BH (2002) The biochemistry and medical significance of the flavonoids. Pharmacol Ther 96:67–202
Hegazi AG, Abd El Hady FK, Abd Allah FAM (2000) Chemical composition and antimicrobial activity of European propolis. Zeitschr Fur Naturforsch 55:70–75
Hertog MGL, Hollman PCH, Hertog MGL, Katan MB (1992) Content of potentially anticarcinogenic flavonoids of 28 vegetables and 9 fruits commonly consumed in the Netherlands. J Agric Food Chem 40:2379–2383
Hollman PCH, Arts ICW (2000) Flavonols, flavones and flavanols—nature, occurrence and dietary burden. J Sci Food Agric 80:1081–1093
Hong J, Smith TJ, Ho CT, August DA, Yang CS (2001) Effects of purified green and black tea polyphenols on cyclooxygenase- and lipoxygenase-dependent metabolism of arachidonic acid in human colon mucosa and colon tumor tissues. Biochem Pharmacol 62:1175–1183
Ingram D, Sanders K, Kolybaba M, Lopez D (1997) Case-control study of phyto-oestrogens and breast cancer. Lancet 350:990–994
Iwashina T (2013) Flavonoid properties of five families newly incorporated into the order caryophyllales (Review). Bull Natl Mus Nat Sci Ser B 39:25–51

Justesen U, Knuthsen P, Leth T (1998) Quantitative analysis of flavonols, flavones, and flavanones in fruits, vegetables and beverages by high-performance liquid chromatography with photo-diode array and mass spectrometric detection. J Chromatogr A 799:101–110
Kamboh AA, Leghari RA, Khan MA, Kaka U, Naseer M, Sazili AQ, Malhi KK (2019) Flavonoids supplementation—an ideal approach to improve quality of poultry products. Worlds Poult Sci J 75:115–126
Kay CD, Mazza G, Holub BJ (2005) Anthocyanins exist in the circulation primarily as metabolites in adult men. J Nutr 135:2582–2588
Keen CL, Holt RR, Oteiza PI, Schmitz HH (2005) Cocoa antioxidants and cardiovascular health. Am J Clin Nutr 81:298–303
Kogawa K, Kazuma K, Kato N, Noda N, Suzuki M (2007) Biosynthesis of malonylated flavonoid glycosides on the basis of malonyltransferase activity in the petals of Clitoria ternatea. J Plant Physiol 164:886–894
Kumar S, Pandey AK (2013) Chemistry and biological activities of flavonoids: an overview. ScientificWorldJournal 162750. https://doi.org/10.1155/2013/162750
Lambert JD, Hong J, Yang GY, Liao J, Yang CS (2005) Inhibition of carcinogenesis by polyphenols: evidence from laboratory investigations. Am J Clin Nutr 81:284S–291S
Lanjewar RD, Zanzad AA, Ramteke BN, Lalmuanpuii TPE, Patankar RB (2009) Incorporation of tulsi (Ocimum sanctum) leaf powder in diet of broilers for quality meat production. Vet World 2 (9):340–342
Lesser S, Cermak R, Wolffram S (2004) Bioavailability of quercetin in pigs is influenced by the dietary fat content. J Nutr 134:1508–1511
Lopez-Lazaro M (2008) Distribution and Biological Activities of the Flavonoid Luteolin. Mini Rev Med Chem 9:31–59
López M, Martínez F, Del Valle C, Orte C, Miró M (2001) Analysis of phenolic constituents of biological interest in red wines by high-performance liquid chromatography. J Chromatogr A 922:359–363
Manach C, Scalbert A, Morand C, Rémésy C, Jiménez L (2004) Polyphenols: food sources and bioavailability. Am J Clin Nutr 79:727–747
Manach C, Williamson G, Morand C, Scalbert A, Rémésy C (2005) Bioavailability and bioefficacy of polyphenols in humans. I. Review of 97 bioavailability studies. Am J Clin Nutr 81:230S–242S
Mandal S, Dutta GK, Nath S (2010) Qualitative phytochemical screening of hygrophila spinosa plant extract. Vet World 3:367
Martens S, Preuß A, Matern U (2010) Multifunctional flavonoid dioxygenases: flavonol and anthocyanin biosynthesis in Arabidopsis thaliana L. Phytochemistry 71:1040–1049
Matthies A, Clavel T, Gütschow M, Engst W, Haller D, Blaut M, Braune A (2008) Conversion of daidzein and genistein by an anaerobic bacterium newly isolated from the mouse intestine. Appl Environ Microbiol 74:4847–4852
Mattila P, Astola J, Kumpulainen J (2000) Determination of flavonoids in plant material by HPLC with diode-array and electro-array detections. J Agric Food Chem 48:5834–5841
Mazza G, Miniati E (2018) Anthocyanins in fruits, vegetables, and grains. Anthocyanins in Fruits, Vegetables, and Grains. CRC, Boca Raton
McDonald MS, Hughes M, Burns J, Lean MEJ, Matthews D, Crozier A (1998) Survey of the free and conjugated myricetin and quercetin content of red wines of different geographical origins. J Agric Food Chem 46:368–375
McIntosh CA, Mansell RL (1997) Three-dimensional distribution of limonin, limonoate a-ring monolactone, and naringin in the fruit tissues of three varieties of Citrus paradisi. J Agric Food Chem 45:2876–2883
Mouly PP, Arzouyan CR, Gaydou EM, Estienne JM (1994) Differentiation of citrus juices by factorial discriminant analysis using liquid chromatography of flavanone glycosides. J Agric Food Chem 42:70–79

Moyers SB, Kumar NB (2004) Green tea polyphenols and cancer chemoprevention: multiple mechanisms and endpoints for phase II trials. Nutr Rev 62:204–211

Naga Mallika E, Prabhakar K, Reddy PM (2009) Low fat meat products—an overview. Vet World 2(9):364–366

Netzel M, Netzel G, Kammerer DR, Schieber A, Carle R, Simons L et al (2007) Cancer cell antiproliferation activity and metabolism of black carrot anthocyanins. Innov Food Sci Emerg Technol 8:365–372

Nowakowska Z (2007) A review of anti-infective and anti-inflammatory chalcones. Eur J Med Chem 8:365–372

Panche AN, Diwan AD (2016) Chandra SR (2016) Flavonoids: an overview. J Nutr Sci 5:e47. https://doi.org/10.1017/jns.2016.41

Pounis G, Di Castelnuovo A, Bonaccio M, Costanzo S, Persichillo M, Krogh V, Iacoviello L (2016) Flavonoid and lignan intake in a Mediterranean population: proposal for a holistic approach in polyphenol dietary analysis, the Moli-sani Study. Eur J Clin Nutr 70:338

Price KR, Rhodes MJC (1997) Analysis of the major flavonol glycosides present in four varieties of onion (Allium cepa) and changes in composition resulting from autolysis. J Sci Food Agric 74:331–339

Rein MJ (2005) Copigmentation reactions and color stability of berry anthocyanins. Dissertation Uni Helsinki

Reinli K, Block G (1996) Phytoestrogen content of foods—a compendium of literature values. Nutr Cancer 26:123–148

Rice-Evans CA, Miller NJ, Paganga G (1996) Structure-antioxidant activity relationships of flavonoids and phenolic acids. Free Radic Biol Med 20:933–956

Risitano R, Currò M, Cirmi S, Ferlazzo N, Campiglia P, Caccamo D et al (2014) Flavonoid fraction of bergamot juice reduces LPS-induced inflammatory response through SIRT1-mediated NF-κB inhibition in THP-1 monocytes. PLoS One 9:e107431

Ruban SW, Kalaikannan A, Appa Rao V (2009) Physico-chemical characteristics of pork sausage during refrigerated storage. Vet World 2:95

Rucker RB (2004) Flavonoids in health and disease. Am J Clin Nutr 74:227–232

Sannomiya M, Fonseca VB, Da Silva MA, Rocha LRM, Dos Santos LC, Hiruma-Lima CA, Vilegas W (2005) Flavonoids and antiulcerogenic activity from Byrsonima crassa leaves extracts. J Ethnopharmacol 97:1–6

Sanoner P, Guyot S, Marnet N, Molle D, Drilleau JF (1999) Polyphenol profiles of French cider apple varieties (Malus domestica sp.). J Agric Food Chem 47:4847–4853

Scalbert A, Williamson G (2000) Dietary Intake and Bioavailability of Polyphenols. J Nutr 130:2073S–2085S

Schroeter H, Heiss C, Balzer J, Kleinbongard P, Keen CL, Hollenberg NK et al (2006) (−)-Epicatechin mediates beneficial effects of flavanol-rich cocoa on vascular function in humans. Proc Natl Acad Sci U S A 103:1024–1029

Senderowicz AM (2003) Small-molecule cyclin-dependent kinase modulators. Oncogene 22:6609

Shen F, Xue X, Weber G (1999) Tamoxifen and genistein synergistically down-regulate signal transduction and proliferation in estrogen receptor-negative human breast carcinoma MDA-MB-435 cells. Anticancer Res 19:1657–1662

Singh P, Anand A, Kumar V (2014) Recent developments in biological activities of chalcones: a mini review. Eur J Med Chem 85:758–777

Stewart AJ, Bozonnet S, Mullen W, Jenkins GI, Lean MEJ, Crozier A (2000) Occurrence of flavonols in tomatoes and tomato-based products. J Agric Food Chem 48:2663–2669

Strissel PL, Strick R (2005) Multiple effects of Bioflavonoids on gene regulation, cell proliferation and apoptosis: natural compounds move into the lime light of cancer research. Leuk Res 29:859–861

Sun C, Wang H, Wang D, Chen Y, Zhao Y, Xia W (2015) Using an FFQ to assess intakes of dietary flavonols and flavones among female adolescents in the Suihua area of northern China. Public Health Nutr 18:632–639

Szkudelska K, Nogowski L (2007) Genistein-A dietary compound inducing hormonal and metabolic changes. J Steroid Biochem Mol Biol 105:37–45
Teixeira A, Eiras-Dias J, Castellarin SD, Gerós H (2013) Berry phenolics of grapevine under challenging environments. Int J Mol Sci 14:18711–18739
Tomás-Barberán FA, Clifford MN (2000) Flavanones, chalcones and dihydrochalcones—nature, occurrence and dietary burden. J Sci Food Agric 80:1073–1080
Traganos F, Ardelt B, Halko N, Bruno S, Darzynkiewicz Z (1992) Effects of Genistein on the growth and cell cycle progression of normal human lymphocytes and human leukemic MOLT-4 and HL-60 cells. Cancer Res 52:6200–6208
Tripoli E, Guardia MA, Giammanco S, Majo DD, Giammanco M (2007) Citrus flavonoids: molecular structure, biological activity and nutritional properties: a review. Food Chem 104:466–479
Tsao TF, Newman MG, Kwok YY, Horikoshi AK (1982) Effect of Chinese and western antimicrobial agents on selected oral bacteria. J Dent Res 61:1103–1106
Tsukiyama RI, Katsura H, Tokuriki N, Kobayashi M (2002) Antibacterial activity of licochalcone A against spore-forming bacteria. Antimicrob Agents Chemother 46:1226–1230
Van Der Sluis AA, Dekker M, Jongen WMF (1997) Flavonoids as bioactive components in apple products. Cancer Lett 114:107–108
Visalli G, Ferlazzo N, Cirmi S, Campiglia P, Gangemi S, Pietro A, Navarra M (2014) Bergamot juice extract inhibits proliferation by inducing apoptosis in human colon cancer cells. Anticancer Agents Med Chem 14:1402–1413
Wang T, Yang Li Q, Shun BK (2018) Bioactive flavonoids in medicinal plants: structure, activity and biological fate. Asian J Pharm Sci 13:12–23
Wang Y, Gapstur SM, Gaudet MM, Peterson JJ, Dwyer JT, McCullough ML (2014) Evidence for an association of dietary flavonoid intake with breast cancer risk by estrogen receptor status is limited. J Nutr 144:1603–1611
Williamson G, Barron D, Shimoi K, Terao J (2005) In vitro biological properties of flavonoid conjugates found in vivo. Free Radic Res 39:457–469
Winkel-Shirley B (2001) Flavonoid biosynthesis. A colorful model for genetics, biochemistry, cell biology, and biotechnology. Plant Physiol 126:485–493
Zainol MKM, Abdul-Hamid A, Bakar FA, Dek SP (2009) Effect of different drying methods on the degradation of selected flavonoids in Centella asiatica. Int Food Res J 16:531–537

Index

S. Ahmad, N. A. Al-Shabib (eds.), *Functional Food Products and Sustainable Health*, https://doi.org/10.1007/978-981-15-4716-4