Chapter 3

Food Preservatives from Plants

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Additional information is available at the end of the chapter

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Abstract

It has long been shown that phytochemicals protect plants against viruses, bacteria, fungi and herbivores, but only relatively recently we have learnt that they are also critical in protecting humans against diseases. A significant amount of medicinal plants is consumed by humans. As food-related products, they additionally improve human health and general well-being. This chapter deals with plant-derived food preservatives. Particular attention has been paid to the following berry fruits: cranberry (*Vaccinium macrocarpon*), bilberry (*Vaccinium myrtillus*), black currant (*Ribes nigrum*), elderberry (*Sambucus nigra*), cornelian cherry (*Cornus mas*) and açaí (*Euterpe oleracea*), as well as the following herbs and spices: peppermint (*Mentha piperita*), basil (*Ocimum basilicum*), rosemary (*Rosmarinus officinalis*), thyme (*Thymus vulgaris*), nettle (*Urtica dioica*), cinnamon (*Cinnamomum zeylanicum*) bark, cloves (*Syzygium aromaticum*) and licorice (*Glycyrrhiza glabra*) as alternative sources of natural antimicrobial and antibiofilm agents with potential use in food industry. Moreover, we present an overview of the most recent information on the positive effect of bioactive compounds of these plants on human health. This chapter is a collection of essential and valuable information for food producers willing to use plant-derived bioactive substances for ensuring the microbiological safety of products.

Keywords: plant extracts, medicinal plants, antimicrobials, antiadhesives, food preservatives, food additives

1. Introduction

According to the 'Plant List'—the first consolidated checklist of the world's plants completed in 2010—there are up to 1 million plant species on Earth, of which around 350,000 have accepted names. Due to the fact that new species are still being identified, calculating anything like an accurate number is further complicated by many examples of the same species in different areas being known by different names. It is estimated that the total number of plants is of the order of 400,000 species. Despite such a great biodiversity, only 80,000 are edible for humans and animals, of which 30 produce 95% of human calories [1, 2]. Furthermore, a significant number of known plants are not only a source of nutrients but also find use as remedies for health problems. For centuries, plants have been known as a sources of bioactive compounds usable to fight health issues. According to the World Health Organization report released in 2003, over 50% of the population of Europe, North America and other industrialized regions have used complementary or alternative medicine at least once. What is more, traditional herbal preparations account for 30–50% of the total medicinal consumption in China. Moreover, the global market of herbal medicines stands at over $ 60 billion annually and generates increasing interest [3].

2. Medicinal plants through ages

The importance of medicinal plants was acknowledged at least 50,000 years ago, as evidenced by numerous archaeological excavations. However, the oldest known medical document—the Ebers papyrus—is dated to the fifteenth century BC. This document contains more than 800 recipes of various medicines from herbs: extracts, lotions and liniments [4, 5]. It is assumed that the oldest document describing medicinal plants used in China and the Far East is the Pent-Sao book. A copy of this chapter, dated seventh century AD, describes nearly 400 herbs from which juices, infusions and ointments were produced. It is worth mentioning that one of the most respected plant materials was Chinese ginseng (*Panax ginseng*), considered to be a drug for immunity, strengthening and energizing [6]. India is also known for its traditional medical systems. One of them—Ayurveda—is found mentioned in the ancient Vedas. The Ayurvedic concept developed between 2500 and 500 BC. The name means 'science of life', and Ayurvedic is also called the 'science of longevity'. The concept is based on the natural treatment methods to cure many common diseases such as food allergies. In general, Ayurvedic is a system based on health care and long life [7]. Herbal medicine in Europe was discovered much later, and the cradle of this field was Greece. Hippocrates of Kos is considered to be the father of phytotherapy, as his work *Corpus Hippocratium,* released after his death, contained information about the beneficial effects of more than 400 plants [8]. In later years (370–287 BC), Theophrastus of Eresos, considered to be the father of botany, described more than 500 plants. However, much more important, in this field, was a five-volume work of Dioscorides—*De Materia Medica* (40–90 AD), considered as one of the most prominent books on herb treatment [9]. On the other hand, the most famous of the Romans was Claudius Galenus, called Galen (130–200 AD), who described 450 plants, claiming that the health effect depends on the form in which the medication is taken. Until the fifteenth century, medicine was based on the recipes described by Galen, and today, medications obtained by crushing and extraction of the plant material are called 'galenic' [10]. However, with the fall of the Roman Empire, the development of herbal medicine has been slowed down. In later centuries, the Arabs introduced new medicinal plants and forms of medicine such as spirit-based syrups. They were the first one to begin using natural dyes and flavourings such as cloves, vanilla, camphor and nutmeg. Avicenna was considered to be the father of medicine of those times—the author of nearly

500 books, among them the *Canon of Medicine* which includes more than 700 herbal medicines [11]. Five centuries later, Paracelsus (1493–1541 AD) disagreed with the views of Hippocrates, Galen and Avicenna. In his opinion, life processes have the character of a chemical transformation; thus, the whole plant is not needed in treatment of a disease, only the specific substance. In that way, phytotherapy was divided in two directions: Galleons—based on extracts, ointments, juices and stocks—and Paracelsus—based on chemical compounds extracted from plants. As a result, a few centuries later, in 1804, the first alkaloid—morphine—was extracted. To this day, both directions are extremely important elements in medicine and daily life [12, 13]. As a consequence, scientists worked not only on the separation of chemical compounds from plants but also on their chemical synthesis. For example, despite the fact that salicylic acid was obtained in a form of an extract from a bark of a willow, the component was synthesized in 1859 by Hermann Kolbe. His discovery is considered to be the beginning of the pharmaceutical industry [14].

The field of pharmaceutical drugs as we know today is based on the historical use of plants. Valuable sources of that are ancient and medieval texts written by explorers who had a combined interest in botany and medicine. The ethnopharmacological knowledge gained from indigenous peoples of a particular region is still used in the search for new medicines. Compounds originating from the plant kingdom of the world make up a framework from which novel drugs are developed. What is more, the importance of plants and the biodiversity also results from the fact that bioactive compounds found in the wild may not be reproducible in the laboratory [15]. The example of this strategy is the identification of artemisinin–antimalarian agent for the discovery of which Tu Youyou received the Nobel Prize in Physiology or Medicine in 2015 [16]. Sweet wormtree (*Artemisia annua*)—the plant, from which the compound was extracted–has been well known in the Chinese medicine since 200 BC. A great number of traditional drugs commonly used in Western medicine are derived from plants, so it comes as no surprise that plants remain an important source of starting material for discovery and commercial use. What is more, plants have attracted scientific interest because 60% of the antimicrobial drugs discovered in the past few decades are of natural origin [17].

It has long been shown that phytochemicals protect plants against viruses, bacteria, fungi and herbivores, but only relatively recently, we have learnt that they are also critical in protecting humans against diseases. Significant part of medicinal plants is consumed by humans, and as a food, it additionally improves human health and well-being in general. It is well known that a diverse array of herbs, vegetables, fruits and grains, besides having nutrients, vitamins and minerals, also possess a large variety of biologically active compounds. These bioactive components as well as their sources as a functional food have recently gained much attention and publicity. The term 'functional food' was first introduced in Japan and refers to foods which, in addition to basic essential nutrients, also contain ingredients beneficial to human health that for example reduce the risk of chronic diseases, promote health and extend longevity [15]. Therefore, the primary function of food is not only to satisfy hunger and to provide the necessary nutrients but also to prevent diseases and to improve physical and mental well-being. What is more, a growing number of consumers are becoming aware of functional foods and its beneficial properties. Therefore, it is considered that functional food is a long-term trend with an important market potential, which is conditioned by the expectations of consumers. Taking this into account, more and more recent innovations are increasingly being used. Food industry innovations can be classified as the following: (1) new food ingredients and materials, (2) innovations in fresh foods, (3) new food processing techniques, (4) innovations in food quality and (5) new packaging methods [18]. As a result, more and more completely new products based on natural additives, in the form of fruit juice or herbal extracts, previously considered as medicinal or unattractive in terms of sensory, are available on the market. Moreover, food manufacturers have realized that besides the fulfilment of health-related consumer expectations, they can use the natural source of bioactive compounds for their purposes [19]. With the increased negative attitudes of consumers to chemical food additives such as preservatives, acidity stabilizers or food colourings, fruit juices and herbs extracts have gained in importance fulfilling all of these functions. The application of natural plant food preservatives with additional potential as health-promoting agents is especially interesting [20]. What is more, natural plant-origin, antimicrobial compounds have been investigated as alternatives to synthetic ones for preserving food quality, owing to their effectiveness against food spoilage and foodborne pathogens [21].

3. Bioactive compounds

Metabolites produced by each living cell can be generally divided into two groups: primary metabolites (PMs) and secondary metabolites (SMs). PMs are the chemicals aimed at growth and development and include carbohydrates, amino acids, proteins and lipids. SMs are characterized as compounds believed to help plant to increase overall ability to survive and overcome local challenges by allowing them to interact with their surroundings. Most of bioactive compounds of plants are produced as secondary metabolites, giving plants their colour, flavour and aroma. The simplest definition of plant origin bioactive compound is 'secondary plant metabolites eliciting pharmacological or toxicological effects in human and animals'. Bioactive compounds are present in all plant material: vegetables, grains, legumes, beans, fruits, herbs, roots, leaves and seeds. They are largely responsible for the medicinal properties and health benefits of herbs, but also for poisonous and toxic effects of others [22, 23].

Despite the fact that classification of bioactive compounds in different categories and subcategories is still inconsistent, they can be divided into three main categories: (1) terpenes and terpenoids (25,000 types), (2) alkaloids (12,000 types) and (3) phenolic compounds (PC) (8000 types) [24]. Basing on unique structural characteristics, and thus on the way of their biosynthesis, as well as function, bioactive compounds belong to one of a number of families. There are four major pathways for biosynthesis of SM: (1) shikimic acid pathway; (2) malonic acid pathway; (3) mevalonic acid pathway and (4) non-mevalonate pathway [25]. Alkaloids are generally produced by aromatic amino acids (shikimic acid pathway) and by aliphatic amino acids. PC are synthesized through two pathways: shikimic acid pathway and malonic acid pathway, while terpenes are synthetized through mevalonic and non-mevalonate acid pathways [23]. The overall classification of bioactive compounds of plants with examples is shown in **Figure 1**.

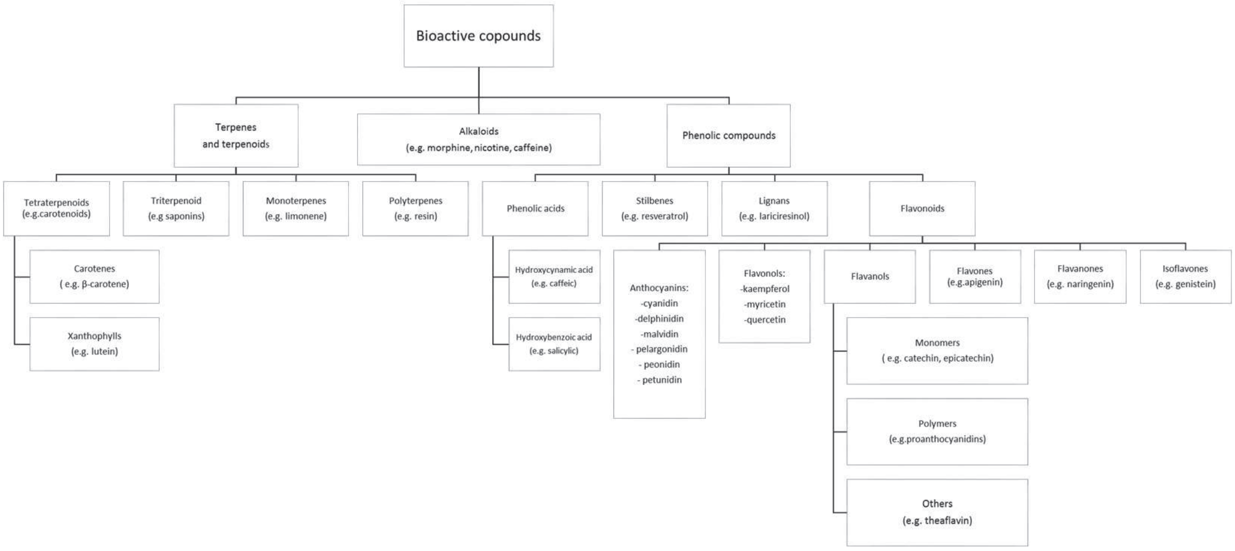

Figure 1. General classification of bioactive compounds of plants.

Phenolic compounds are widely distributed, and an important group of compounds occurs in plants. Polyphenol family contains about 8000 structurally different compounds, commonly found in fruits, vegetables, seeds, flowers and leaves. They are generally categorized as phenolic acids and derivatives, flavonoids, tannins, stilbenes, lignans, quinones and others based on the number of phenolic rings and of the structural elements that link these rings. Biosynthesis of mono and polyphenolic compounds is carried out from carbohydrates by way of shikimic acid, phenylpropanoid and flavonoid pathways [26]. Generally phenolic acids contain two distinguishing constitutive carbon frameworks: the hydroxycinnamic and hydroxybenzoic structures. The first group of phenolic acids includes ferulic, chlorogenic, sinapic, caffeic and p-coumaric acids, while the second one contains gallic, syringic, protocatechuic and vanillic acids. Other polyphenols are also considered as phenolic acids: capsaicin, rosmarinic acid, gingerol, gossypol, ellagic acid and cynarin [27]. It is worth noting that caffeic, p-coumaric, vanillic, ferulic and protocatechuic acids are widely distributed in nearly all plants. Red fruits, especially berries: blueberry (*Vaccinium corymbosum*), blackberry (*V. myrtillus*), chokeberry (*Aronia melanocarpa*), strawberry (*Fragaria virginiana*), red raspberry (*Rubus idaeus*), elderberry (*S. nigra*) and black currant (*R. nigrum*), are a rich source of phenolic acids (**Figure 2**).

Another group of phenolic compounds are **flavonoids** which include flavonols, flavanols, flavones, flavanones, isoflavones and anthocyanins [28, 29]. The most widespread of all the groups are flavonols conjugates with over 200 different sugar conjugates of kaempferol. In

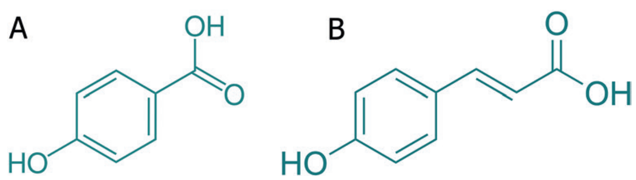

Figure 2. Representatives of phenolic acids. A—4-hydroxybenzoic acid; B—coumaric acid.

addition to kaempferol, flavonols also include myricetin, quercetin, morin, galangin and isorhamnetin and most commonly occur in the form of O-glycosides (**Figure 3**). They are present in a wide range of food such as fruit (cherries, blueberries, apples), vegetables (broccoli, tomato), beverages (red wine), herbs and spices (caraway, cumin).

On the other hand, flavones appear in a limited number of raw plant materials and can be found in parsley, celery, thyme, tea, legumes and certain other herbs. The major flavones are apigenin, luteolin, baicalein, chrysin and their derivatives. Tangeretin, nobiletin and sinensetin, the most hydrophobic of all of the flavonoids, also belong to this group [26]. Naringenin and hesperetin as well as their glycosides (naringin, hesperidin) are flavanones present mainly in citrus fruits (oranges, lemons), grapes, and medicinal herbs belonging to the family: *Rutaceae*, *Rosaceae*, and *Leguminosae* [30]. Another, very important group are flavanols which occur as simple monomers of (+)-catechin or (-)-epicatechin, as well as in hydroxylated (gallocatechins) and esterified (gallic acid) forms (**Figure 4**).

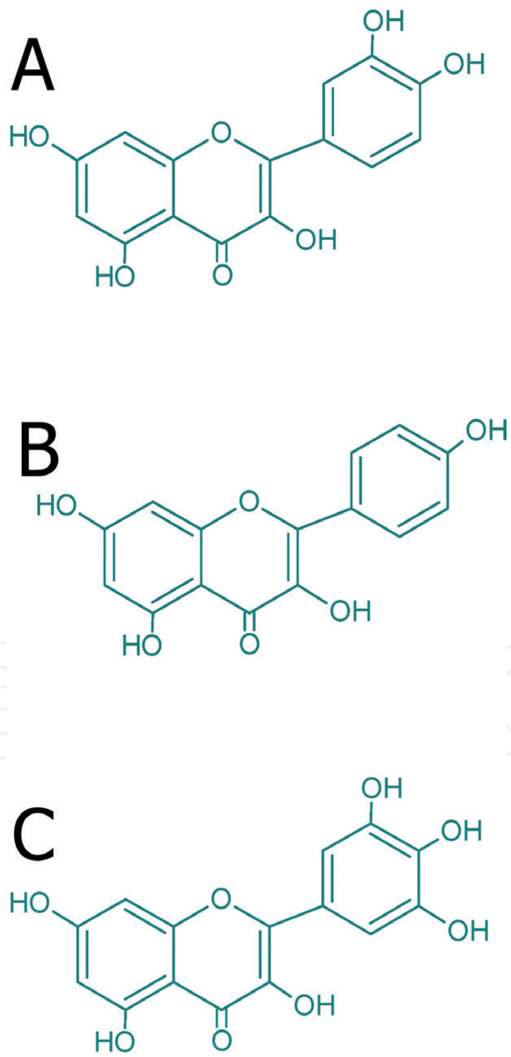

Figure 3. Typical flavonols: A—quercetin; B—kaempferol; C—myricetin.

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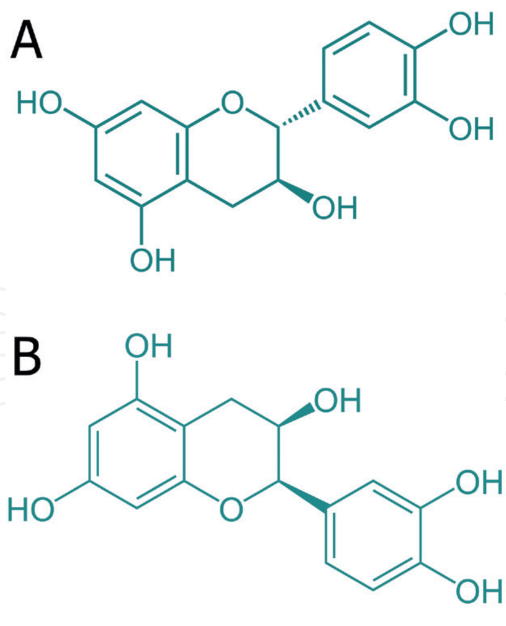

Figure 4. Structures of A—(+)- catechin; B—(-)-epicatechin.

The most important among flavanols are catechin, epicatechin, epigallocatechin, epicatechin gallate and epigallocatechin gallate. They are present in tea (mainly green tea), apples, grapes, berries and cocoa. Anthocyanins, including cyanidin, delphinidin, malvidin, peonidin and pelargonidin as well as their glycosides, are widely distributed in fruits giving them a characteristic colour depended on their pH. Therefore, in addition to health properties, they arouse interest as food colourings [31] (**Figure 5**).

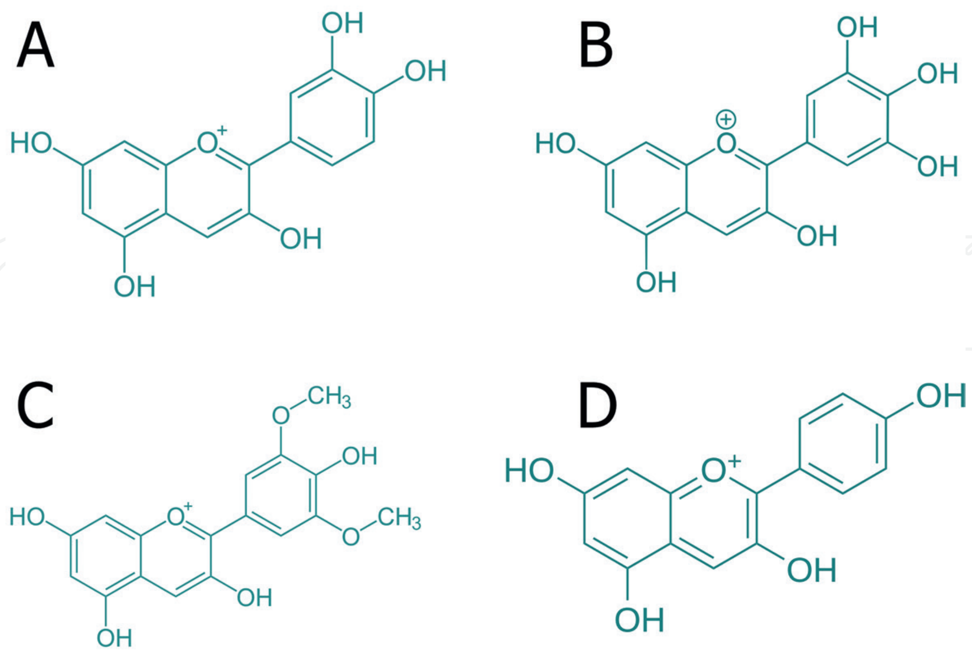

Figure 5. Representatives of anthocyanins: A—cyanidin; B—delphinidin; C—malvidin; D—pelargonidin.

Alkaloids are the next class commonly found in plants. General definition has been suggested in 1983 by Pelletier, and it was 'cyclic compound containing nitrogen in negative oxidation state which is of limited distribution in organisms'. Despite the diversity of alkaloids, they show a similarity in the chemical structure: (1) alkaloids contain nitrogen, in most cases derived from several amino acids; (2) exhibit alkaline pH and (3) they have no basic forms like quaternary compounds and N-oxides [32]. The most often used classification of alkaloids is so-called (1) true alkaloids—atropine, nicotine and morphine; (2) protoalkaloids—adrenaline and ephedrine; and (3) pseudoalkaloids—caffeine, theobromine and theacrine. On the other hand, based on the biosynthesis, alkaloids can be divided into indole alkaloids (tryptophan derived, e.g. ergometrine), piperidine (lysine derived, e.g. lobeline), pyrrolidine (ornithine derived, e.g. hygrine), phenylethylamine (tyrosine derived) and imidazole (derived from histidine, e.g. pilocarpine). It is believed that about 14–20% of plant species contain alkaloids. Main representatives are plants belonging to the families: *Solanaceae* (e.g. *Nicotiana tabacum* and *Datura stramonium*), *Papaveraceae* (e.g. *Papaver somniferum*), *Ranunculaceae* (e.g. *Hydrastis canadensis*), *Erythroxylaceae* (e.g. *Erythroxylum coca*), *Rubiaceae* (e.g. *Pausinystalia johimbe*) and *Campanulaceae* (e.g. *Lobelia inflate*). Alkaloids in plants are considered to be a growth regulation factor, serve as a reserve substance as well as play an important role in plants [33]. Alkaloids are generally used in therapeutics and pharmacology. They show a wide range of biological properties: anti-inflammatory, antidepressant, antitumor, antiviral, antihypertensive, but also antimicrobial and antimalarial [34].

Terpenes, also called terpenoids, are the most diverse class of natural bioactive compounds. It is believed that this class can count up to 40,000 different chemicals [35]. They can be classified into many categories based on the number of carbon atoms as well as the presence of isoprene residues (IPR): (1) monoterpenes consist of 10 carbon atoms, or two IPR; (2) sesquiterpenes contain 15 carbon atoms, or three IPR; in the composition of (3) diterpenes consist of 20 C atoms, or four IPR; (4) triterpenes consist of 30 C atoms, or six isoprene units, while in the composition of (5) tetraterpenes there are 10 more carbon atoms, or two more isoprenes. The last group polyterpenes are composed of large number of IPS. Although terpenes are secondary metabolites, they have a well-characterized function in plants growth. For example, gibberellins (diterpenes) are plant hormones, sterols (triterpene derivatives) are responsible for cell stabilization, while carotenoids show protective activities against photo-oxidation. The best known among this class of compounds are carotenes and oxycarotenoids (xanthophylls) belonging to tetraterpene family. Carotenoids, such as β-carotene, lutein, lycopene or zeaxanthin, are lipid-soluble colour pigments occurring in vegetables and fruits, giving them a yellow, orange and even a red colour [26]. On the other hand, some terpenes are toxins and play important defensive roles against many insects and mammals. Pyrethroids and monoterpene esters, from *Chrysanthemum* spp., show strong insecticidal activities. However, it is believed that the most important from all of the terpenes are volatile monoterpenes and sesquiterpenes known as essential oils (EOs). They occur mainly in herbs and spices, as well as some fruit, giving them a characteristic aroma. Peppermint (*M. piperita*), lemon (*Citrus limon*), basil (*O. basilicum*), cinnamon (*C. zeylanicum*) and rosemary (*R. officinalis*) are the examples of plants that are rich sources of essential oils. EOs are well-known bioactive compounds used in aromatherapy, microbiology and agroindustry. It has been shown that terpenes exhibit various pharmacological properties such as anti-inflammatory, anticarcinogenic, antitumor, antibacterial, antimalarial, antiviral, antibacterial as well as hepatoprotective [24–26].

Saponins are a group of compounds which attract attention. Structurally, they can be divided into triterpenoids or steroids. They contain a triterpene or steroid aglycone and attached sugar chain(s), mainly consisting of rhamnose, xylose, arabinose, galactose and fucose. Their amphoteric nature results from the presence of hydrophobic aglycone and hydrophilic sugar chains [36]. These molecules are responsible for the unique properties of saponins: emulsifying, foaming and detergenic properties. The source of steroidal saponin in nature is *Lilianae* (monocotyledons), while triterpenoid is commonly found in *Dicotyledoneae* (dicotyledons). In plants, they accumulate mainly in the bark, roots and leaves of the plants belonging to *Agavaceae*, *Leguminosae*, *Rosaceae*, *Caryophyllaceae* and *Umbelliferae* families [37]. The main representatives of plants characterized by a rich composition of saponins are as follows: Chinese honey locust (*Gleditsia sinensis*), soapwort (*Saponaria officinalis*), Mongolian milkvetch (*Astragalus propinquus*), ginger (*P. ginseng*), Yucca (*Yucca schidigera*) and soapbark (*Quillaja saponaria*). The last two are traditionally used as detergents (*Q. saponaria*) or in animal nutrition in order to reduce faecal odours (*Y. schidigera*). Saponins are compounds exhibiting insecticidal, anthelmintic, molluscicidal as well as antiviral, antibacterial and antifungal activities in plants [38]. Saponins show anticancer properties, while these from *Androsace umbellate* are reported as inductors of cell apoptosis and inhibitors of cancer cells [39, 40]. What is more, saponins from *Yucca* show an inhibition of food-spoilage yeast *Debaryomyces hansenii*, *Pichia nakazawae*, *Zygosaccharomyces rouxii*, *Candida famata* and *Hansenula anomala* [41]. In recent years, saponins sparked interest as a natural, environment friendly additives/ingredients. For example, *Y. schidigera* are commonly used in Japan as an additive against yeasts contaminating cooked rice, pickled vegetables or fish meat [42]. Moreover, it was found that yeast treated with saponin extract from *Q. saponaria* showed increased cell membrane permeability, as a result facilitating the preparation of yeast salt-free lysates much easier [43].

Due to the richness and variety of bioactive substances contained in plants and their positive effects on human health, they constitute important raw materials used in a variety of industries. In view of their promoting properties, such as antioxidant, anti-inflammatory, anticancer, antimutagenic, antiallergenic, antifungal, antibacterial and many others, research has been intensified towards fruit, vegetables, plants, herbs and spices which will provide an attractive and functional addition to food products.

4. Herbs and spices

Herbs and spices have been playing a key role in the daily life of mankind since the ancient times. They are derived from various parts of plants from all over the world. Herbs are generally fresh or dried leaves of plants, while spices are divided into four groups: (1) pungent species, (2) aromatic seeds, (3) aromatic barks and (4) coloured species [44]. It is considered that about 400 herbs and spices are commonly used around the world. It is speculated that a much larger proportion of human population uses herbs and spices as therapeutic remedies, compared to prescription pharmaceuticals. The characteristics of herbs are conditioned by their chemical composition, e.g. its aroma and flavour depend on the volatile oils such as monoterpenes [45, 46]. Among other things, these features made them recognized as a food, food additives and in the manufacturing of cosmetics and pharmaceuticals. What is more, global awareness of health and environmental issues, especially in the developed countries, caused increased demands for medical herbs and spices as well as food products containing these plant materials. Increasingly common are new herbs or mixtures of herbs designed to improve the health of consumers. Due to the popularity of functional and ecological foods, and as well as increasing consumer awareness about the impact of diet on human health, the pro-healthy herbs are used in food production [46].

There is no doubt herbs and spices of natural origin show the extraordinary properties and advantages for human population. Due to their natural origin, they are generally considered as safe for consumption and thus can be used in food production. The consequence of rising consumer awareness is the demands for high-quality foods. What is more, there are also concerns about microbiological food safety due to the occurrence of new food-borne pathogens and spoilage microorganisms. Therefore, food manufacturers are aware of the limited use of synthetic preservatives, and they are looking for new sources of bioactive compounds that exhibit three roles: (1) meet the expectations of the new trends of healthy food; (2) will be characterized by antimicrobiological properties and (3) show other functions of food additives (acidity stabilizers, dyes or other) [47]. Further part of the chapter provides an overview of the literature on the properties of selected herbs and spices, which are a potential source of food additives. Herbs have been chosen with regard to their antimicrobial properties and health benefits of their regular consumption.

4.1. Peppermint (*M. piperita*)

Description. Peppermint (*M. piperita*) is a natural hybrid of watermint (*Mentha aquatic*) and spearmint (*Mentha spicata*) belonging to family *Lamiaceae*. The herb is native to Europe, but nowadays, it is commonly found around the world and used as a pharmaceutic and cosmetic material, as well as a food additive, mainly in order to enrich the products in fresh, mint flavour and aroma. In traditional medicine, peppermint essential oils are commonly used. It is commonly found as one of the compounds of tea, but the extract of peppermint is also consumed [48]. *M. piperita* leaves are popularly known as refreshing additive in beverages. According to Food and Agricultural Organization of United Nations (FAO), world's production of peppermint in 2010 reached more than 80,000 tons. The biggest global producer was Africa—89% of the amount [49].

Bioactive compounds *M. piperita* is mostly known for its essential oils, and, hence, volatile components, which are often used in cosmetics, pharmaceutics and food industry. It is considered that major compounds of peppermint EOs are menthone (approximately 30%) and menthol (25%). Other compounds like menthofuran, limonene, β-phellandrene, isomenthone, menthol acetate, pulegone, β-caryophyllene, neomenthol and germacrene D are encountered at much lower concentration [50, 51]. Phytochemicals detected in the *M. piperita* extracts are also rosmarinic acid, ferulic acid, gallic acid, vanillic acid, p-coumaric acid, caffeic acid, syringic acid, (+)-catechin, (-)-epigallocatechin gallate, eriocitrin, hesperidin and luteolin-7-O-rutinoside [48, 52]. Generally, 50% of all of the *M. piperita* bioactive compounds are flavonoids, followed by about 42% phenolic acids, and 2.5% of lignans and stilbenes. According to Fecka and Turek, 2 g of peppermint can provide 88 mg of phenolic acids, but the value depends on the type of the product [53].

Health benefits Research on the health-benefiting activities of peppermint showed that one in eight plants exhibits strong activity in suppressing the effect of okadaic acid which promotes tumour formation [54]. Extract of *M. piperita* suppresses mutagenicity of human carcinogens formed in cooked meat. What is more, methanol extract from peppermint is cytotoxic to L1210 cancer cells. Extract of mint also reduces lungs carcinogenicity and mutagenicity [55]. Other studies suggest that *M. piperita* can affect the bioavailability of certain drugs. Furthermore, flavonoids from this herb show antiallergic effects in research with rat peritoneal mast cells. It is believed that luteolin-7-O-rutinoside is an especially potent compound. Both the aqueous extracts and peppermint oils exhibit potent antiviral properties towards herpes simplex virus (HSV), influenza, vaccinia virus, suppressing replicative ability of HSV-1 [56]. It has been found that virulence of both herpes simplex virus 1 and 2 is inhibited by peppermint oil. It has also been shown that bioactive compounds contained in herbs are characterized by gastrointestinal activities (stimulating choleretic activity), antiallergenic actions inhibiting sneezing and with menthol from peppermint a significant enhancement of the nasal sensation [52].

Antimicrobial activity It has been documented that *M. piperita* extracts and EOs are characterized by broad spectrum of antibacterial activities against gram-positive and gram-negative pathogens as well as antifungal activities against yeasts and moulds. In the study of Singh et al., it was found that gram-positive bacteria such as *Staphylococcus aureus* and *Staphylococcus pyogenes* are more sensitive to essential oil compared to *Escherichia coli*. Authors also established that the growth inhibition was compared with gentamycin [57]. Mint oil also had bactericidal effect against *Staphylococcus mutans*, *Salmonella typhimurium*, *Pseudomonas aeruginosa* and *Shigella* spp. It has been confirmed that gram-negative bacteria such *P. aeruginosa* are less sensitive to mint oil that other tested bacterial strains [58]. On the other hand, Pramila et al. noted that methanol extract of *M. piperita* showed stronger activity against *E. coli* compared to *Staphylococcus* and *Acinetobacter* strains [59]. Mint oil was also effective in inhibiting *Salmonella enteritidis* in cucumber salads, tzatziki yoghurts, as well as cod's roe salad [60]. The *M. piperita* EOs and ethanol extract showed antifungal activity against *Candida* spp.: *Candida tropicalis, Candida albicans*, *Candida glabrate* and *Candida parapsilosis*, but its infusion did not have any antifungal properties not only to them but also moulds: *Aspergillus niger*, *Aspergillus flavus, Aspergillus parasiticus*, *Rhizopus solani*, *Alternaria alternata* [61]. What is more, peppermint oils and extract showed anti-adhesive and antibiofilm properties against food spoilage bacteria *Asaia lannensis* and *Asaia bogorensis* as well as rods *P. aeruginosa*, bacilli *Listeria monocytogenes* and yeasts *C. albicans*, *Candida dubliniensis* [62–65].

4.2. Basil (*O. basilicum*)

Description Another representative of a medical herb belonging to the family *Lamiaceae* is basil (*O. basilicum*), originating from the warm tropical climates of India, Africa, Asia as well as Mediterranean Europe. *O. basilicum* is one of the 150 species, widely cultivated worldwide, due to its use in cooking and folk medicine for treating headaches, coughs and kidney malfunctions. In everyday life, basil is a popular flavouring agent, an additive to medications, cosmetics, perfume and food products [66, 67].

Bioactive compounds Similar to peppermint (*M. piperita*), basil belongs to the aromatic plants, and therefore, the most common mixture of bioactive compounds derived from this plant is essential oils. EOs of *O. basilicum* mainly contain eugenol, estragol, methyl cinnamate, linalool, geranial and neral, but the composition can differ dependent upon harvest dates and growth condition. Other compounds identified in basil oils are E-caryophyllene, aromadendrene, α-humulene, terpinen-4-ol, γ-terpinene and camphor [66]. Typical methanolic basil extracts mainly contain: rosmarinic acid—as the dominant phenolic acid, chicoric acid—recently discovered in basil leaves, and caffeic and caftaric acids—at lower concentrations [67, 68]. On the other hand, ethanolic extracts of basil, in addition to rosmarinic, chicoric and caftaric acids, contain chlorogenic, gentisic, ferulic and p-coumaric acids, as well as β-carotene and lutein-zeaxanthin. In the study of Vlase et al., it was documented that the extract is a source of quercetin-3-glucoside, quercetin-3-rutinoside, quercetin-3-rhamnoside as well as luteolin [69].

Health benefits Due to the phenolic compounds as well as essential oils, basil is widely used as an anti-inflammatory, insecticidal and nematicidal agent. Traditionally, decoction of *O. basilicum* root is used as a drink for stomach pains and as an enema in constipation. On the other hand, tea from basil leaves is commonly inhaled for nasal and bronchial catarrh, and as a sudorific and stomachic agent [66]. What is more, some scientific literature reports that basil shows antidiabetic, adaptogenic, cardioprotective, immunostimulatory, anticarcinogenic and hepatoprotective properties [70].

Antimicrobial activity The ethanolic extracts of *O. basilicum* showed stronger antibacterial activity against gram-positive *S. aureus* than against gram-negative *L. monocytogenes*, *E. coli*, *S. typhimurium* and yeasts *C. albicans* [71]. On the other hand, the results obtained for essential oils suggest that gram-negative bacteria such *E. coli* and *P. aeruginosa* are characterized by higher sensitivity to bioactive compounds from basil [71]. Sienkiewicz et al. documented that basil oil exhibited strong antibacterial activity against clinical strains of *E. coli*, including β-lactamase positive [72]. It is considered that mainly linalool and eugenol are responsible for the antibacterial activity of basil EOs. What is more, essential oils from basil show antifungal activity against common plant pathogens: *Glomerella cingulata*, *Fusarium solani*, *A. alternata* and *Fulvia fulva* [73]. Basil EOs were tested as a natural fungicide against *Penicillium* and *Aspergillus* strains isolated from sausage [74]. Antimicrobial activity of *O. basilicum* essential oils was also shown against *S. enteritidis* both *in vitro* and in a food model by Rattanachaikunsopon and Phumkhachorn [75]. The results obtained by Carovic-Stanko et al. indicated that *Ocimum americanum* shows antimicrobial activity, against *E. coli* 0157:H7, *Enterobacter faecalis*, *Enterobacter faecium*, *Proteus vulgaris*, *S. aureus* and *Staphylococcus epidermis*

[76]. Due to the wide use against bacteria and fungi, basil oil is widely considered as a natural agent improving food safety.

4.3. Rosemary (*R. officinalis*)

Description Rosemary (*R. officinalis*), 1 m high, evergreen shrub with upright stems, whitish-blue flowers and dark green leaves, belongs to the family *Lamiaceae*. The herb is commonly cultivated in Mediterranean countries: Spain, Tunisia, France and Italy. Due to its intense pleasant smell reminiscent of pine, rosemary is widely used in traditional medicine and cosmetics and as a food flavouring [77].

Bioactive compounds The chemical analysis of the essential oil obtained from rosemary indicated that the herb is a rich source of monoterpenes and contains mainly: eucalyptol (1,8-cineole), camphor, β-pinene, borneol, limonene as well as camphene. What is more, according to Kontogianni et al., *R. officinalis* also contains isorhamnetin-3-O-hexoside, rosmarinic acid, carnosic acid and the triterpenic acids (oleanolic, ursolic, betulinic), as well as homoplantaginin [78]. On the other hand, extract of rosemary contains flavonol (isorhamnetin), flavones (luteolin, apigenin, hispidulin) and phenolic acids (hydroxybenzoic, hydroxycinnamic derivatives). Additionally, in the chapter of Mena et al., luteolin-rutinoside, luteolin-hexoside, isorhamnetin-3-O-hexoside, isorhamnetin-rutinoside, eriodictyol, luteolin hesperetin and epirosmanol have also been detected [79].

Health benefits Rosemary is generally an important source of bioactive compounds exhibiting several health-benefiting activities. In traditional medicine, oils, water and ethanolic extract of rosemary are commonly used as an agent for digestive, astringent, diuretic and diaphoretic problems, as well as mild analgesic and for physical and mental fatigue. Moreover, phytochemical composition contained in the herb showed anti-inflammatory, antidepressant, antiatherogenic, hepatoprotective, nephroprotective, antiobesity and anticancer properties. It has been documented that bioactive compounds, mainly carnosic acid, rosmarinic acid and carnosol, showed high antioxidant activity. What is more, essential oil of rosemary, due to monoterpenes such as 1,8-cineole, camphor and pinene content, is used as an antimicrobial biopreservative in food production [79–82].

Antimicrobial activity High bioactive compound content in essential oils and extract has been documented as a strong antimicrobial agent. Rosemary EOs exhibit antifungal activity against *Fusarium graminearum* (cereal pathogen), α-pinene and 1,8-cineole contained in the oil show activity against, *C. albicans*, and *A. niger* [81]. Rosemary oil also exhibits bacteriodical and bacteriostatic activity against *S. aureus*, *Bacillus subtilis* and *P. aeruginosa* [83]. The antibacterial, fungistatic and fungicidal activities of *R. officinalis* were also noted in the article of Bozin et al. The authors showed that rosemary EOs had strong activities against *C. albicans*, *Trichophyton tonsurans*, *Trichophyton rubrum*, *Epidermophyton floccosum*, *Microsporum canis*, *P. aeruginosa*, *E. coli*, *Salmonella typhi*, *S. enteritidis*, *Shigella sonnei*, *Micrococcus flavus*, *Sarcina lutea*, *S. aureus*, *Staphylococcus epidermidis* and *B. subtilis* [84]. Antifungal activity of rosemary was also studied against fresh dough spoilage *Aspergillus* spp. and *Penicillium* spp., and microencapsulation retained the antimicrobial property of the EOs [85]. Antimicrobial activity of essential oils depends on their volatile chemicals, such as aromatic compounds and polyphenols. The mechanism of action includes direct activity on cytoplasmic membrane, causing changes in lipid bilayer, and as a result disrupting membranes, which finally leads to leakage of the cell content [58].

4.4. Thyme (*T. vulgaris*)

Description Thyme (*T. vulgaris*), also called as common thyme, German thyme or garden thyme, is the next representative of the *Lamiaceae* family. This herb is native to Mediterranean countries in Europe. Thyme is a woody-based evergreen herb with aromatic green leaves and pink flowers. *T. vulgaris* is used as a groundcover in gardens, but is much more valuable as a flavouring to rabbit, boar, and lamb meats, giving them a spicy taste. In folk medicine, thyme was used as an infusion or an additive for baths for treatment of skin diseases, as well as carminative, and a sedative medicament [86].

Bioactive compounds Similar to other aromatic herbs, bioactive compounds from thyme can be obtained, in both aqueous form or alcoholic extracts and essential oils. *Thymus* EOs are generally a mixture of monoterpenes, mainly thymol (approximately 50% of all of the compounds) and carvacrol (10%). Essential oil of thyme is also a source of α-terpineol, γ-terpinene, linalool, camphor and caryophyllene [86]. What is more, phenolic acids (caffeic, p-coumaric, cinnamic, carnosic, rosmarinic, caffeoylquinic, ferulic and quinic), as well as flavonols (quercetin-7-O-glucoside), flavones (apigenin), flavanones (naringenin) can also be present in methanolic extracts [87]. Steroids, saponins, alkaloids, tannins and flavonoids can also be extracted from thyme using hexane, ethyl acetate and butanol [88].

Health benefits Infusions and decoctions of thyme leaves have been used for thousands of years for treatment of a cold, in a production of tonics, as a medicine in digestive problems, as antispasmodic, expectorant in upper respiratory tract infections, as well as an carminative agent. The herb is also reported to enhance the activity of the superoxide dismutase, an enzyme which has the potential to act as an anti-inflammatory agent [89]. What is more, scientific reports showed that *T. vulgaris* possesses numerous biological properties including antioxidant, antimicrobial and sedative and can be used in gastroenteric and bronchopulmonary disorders [90]. What is more, thymol EOs show antiseptic properties 30 times higher than phenol and thus are used as the main active antiseptic ingredient in chemotherapeutic mouth rinses against gingivitis.

Antimicrobial activity Investigating the antimicrobial activity of thyme essential oil showed that bioactive components are a strong antibacterial and antifungal agents against both food spoilage microflora and photogenic microflora. Essential oil of thyme prevented the growth of gram-negative bacteria *Erwinia amylovora* which is responsible for fire blight disease of apples and pears [91]. Thyme and EOs demonstrated strong inhibitory effects against *Colletotrichum gloeosporioides* and *Rhizopus stolonifera* responsible for the spoilage of storage papaya fruits [92]. In the chapter of Arras and Usai, essential oil of *Thymus* sp. showed strong fungitoxic activity against citrus pathogens: *Penicillium digitatum*, *Penicillium italicum*, *Botrytis cinerea* and *Alternaria citri* [93]. Satya et al. showed the inhibitory effect on *A. niger*, *Cryptococcus neoformans* and *C. albicans.* It is speculated that camphor contained in the oil is mainly responsible for antifungal activity of thyme oil [94]. What is more, the oil vapour of the herb-reduced peach brown rot caused by *Monilinia laxa* increasing the activity of phenylalanine ammonia lyase [95]. *T. vulgaris* extract also showed strong antibacterial activity against food pathogens such as *B. subtilis, Enterobacter cloacae, S. aureus, S. epidermidis, Salmonella typhimurium, S. enteritidis, P. aeruginosa, E. coli, M. flavus and Micrococcus mirabilis* [96].

4.5. Nettle (*U. dioica*)

Description Common nettle (*U. dioica*) is an, up to 2 m high, herbaceous perennial plant belonging to the family *Urticaceae*. The herb is native to Africa, Asia, North America and Europe, but nowadays, it is found worldwide. The name of this green plant comes from *uro*, meaning 'burn', or *urere* meaning 'to sting'. Nettle is characterized by hollow stinging hairs called trichomes occurring on leaves and stems. Trichomes act like needles which in contact with human skin inject acetylcholine, histamine, serotonin, moroidin and formic acid, causing burning and rashes. *U. dioica* has been traditionally used as a source of medicine, food and feed additive and fibres [97].

Bioactive compounds The main source of the bioactive compounds is leaves which, beside phytochemicals responsible for the burning (acetylcholine, histamine, 5-hydroxytryptamine, leukotrienes and formic acid), also contain phenolic acids, flavonoids, fatty acids, terpenes and protein. Among the phenolic acids, chlorogenic, caffeoylmalic, caffeic, gallic and quinic are contained in nettle. *U. dioica* is a rich source of other bioactive compounds: kaempferol, isorhamnetin, quercetin and its derivative, as well as patuletin and its glycosidic derivatives [97]. Essential oil of *U. dioica* contains more than 40 compounds, of which 70% are carvacrol, carvone, naphthalene, (E)-anethole, hexahydrofarnesyl acetone, (E)-β-ionone and phytol [98].

Health benefits Common nettle has been known and used as a medicinal plant since ages. The plant is considered more as a weed than an herb, but at the same time, it is also characterized by a number of pro-health properties, for which it is appreciated. Regular consumption of teas, juices and extracts of *U. dioica* shows immunostimulatory, anti-inflammatory, anticarcinogenic and antioxidant activities. Extracts obtained from different parts of the plant are used in many parts of the world. Leaves are recommended as a nutritional tonic, in the treatment of rheumatic conditions, lower urinary tract infections and for the treatment of allergies. What is more, they are used as expectorants, purgatives, diuretics and haemostatics and for the treatment of eczema, haemorrhoids, bronchitis and cancer. Bioactive compounds contained in nettle extracts may enhance selective gastric functions and protect the gastric mucosa from chemical-induced damage. Roots of the nettle, in the form of extracts, are used to reduce complaints associated with prostate hyperplasia [97].

Antimicrobial activity Phytochemicals contained in the nettle show a broad spectrum of antibacterial activity. Most commonly consumed in the form of teas and infusions, aqueous extract shows antibacterial activity against: *Micrococcus luteus*, *Proteus mirabilis*, *Citrobacter koseri*, *S. aureus*, *S. pyogenes*, *S. epidermidis*, *Streptococcus pneumoniae*, *Enterobacter aerogenes*, *E. coli*, as well as antifungal activity against *C. albicans* [99–102]. *U. dioica* extracts also show bactericidal properties against *Acinetobacter calcoaceticus*, *Bacillus cereus*, *Bacillus spizizenii*, *Vibrio* *parahaemolyticus* and *Klebsiella pneumonia.* What is more, the activity of nettle extract can be compared with antibiotics: miconazole, amoxicillin and ofloxacin [101]. Furthermore, the extract of *U. dioica* also shows inhibitory activities on the *Asaia* spp.—novel beverage spoilage bacteria inhabiting fruit-flavoured mineral water and isotonic drinks. Therefore, nettle is considered as an unconventional additive to this products as a food preservative [103].

4.6. Elder flowers (*S. nigra*)

Description Elderberry (*S. nigra*), also called black or common, is a deciduous shrub reaching up to 6 m high, belonging to the *Adoxaceae* family. The plant is native to sunlight-exposed areas of Asia, Africa, North America and Europe. Every summer, its flowering occurs in the form of white hermaphrodite flowers in large corymbs. The plant is highly valued mainly for the fruit, which will be described in Section 5.4 of this chapter. However, elderflower extracts are used in the beverage industry and as food flavouring as well as in alternative medicine [104].

Bioactive compounds Flowers of elderberry are a rich source of phenolic compounds, containing 10 times more flavonols than fruit. In addition to flavonols (kaempferol-3-glucoside, kaempferol-3-rutinoside, quercetin-3-glucoside, quercetin-3-rhamnoside and flavones such as apigenin), they contain derivatives of caffeic and p-coumaric acids, rutin, lupeol, β-sitosterol, tannic acid and choline [104].

Health benefits The extract of elderberry flowers has been used in traditional medicine for treatment of influenza A and B, colds, as well as an agent against the H1N1 virus. It has been documented that elderberry flower extract can be used as an agent preventing the viral adhesion of host cell receptors. What is more, the positive impact of elderberry flowers was observed in the studies on diabetes, vascular system and obesity. It has been documented that elderberry flower extract decreased fat accumulation, and hence body weight, improving the body mass index. Elderberry may have a role in the prevention and treatment of diabetes—elderberry extract may be responsible for the increase of glucose uptake and increase in the insulin production [105–107].

Antimicrobial activity Despite the fact that in folk medicine elderberry flowers are the raw material for many kinds of ailments, their antimicrobial properties are barely examined. In the studies of Mohammadsadeghi, et al. and Hearst, et al., elderberry extracts exhibit strong antibacterial activity against both gram-negative and gram-positive bacteria such us *P. aeruginosa*, *E. coli*, *Salmonella* spp., *S. aureus* and *B. cereus*. It was also demonstrated that *S. nigra* inhibits the growth of the yeast *C. albicans* [108, 109]. Our study on the antibacterial activity of the elderberry flower ethanolic extract against *A. lannensis* and *A. bogorensis* showed that the tested extract had the strongest activity against these strains. Moreover, the extract exhibited strong antiadhesive properties against all of the tested strains of *Asaia* spp. It was speculated that this broad spectrum of antibacterial activities may be the result of high content of flavonols [103].

4.7. Cinnamon bark (*C. zeylanicum*)

Description Cinnamon (*C. zeylanicum*) belonging to the family *Lauraceae* is a tropical evergreen tree originating from areas of tropical climate in India, Sri Lanka and Burma. Due to that, it is cultivated in Asia, Africa, South and Central America. Tree reaching 10 m in height mostly does not exceed 3 m. The spice is the bark of the tree, which is collected 2–3 times a year during the wet season. The bark is cut into pieces of 3 m in length and approximately 2.5 cm in diameter. Then, the bark is subjected to a short fermentation and next the removal of external and internal phloem. After that, the obtained bark is dried in the sun. During this process, it gains the characteristic yellow-brown colour. Cinnamon is widely used in ethnomedicine and as a flavouring for foods all around the world [110].

Bioactive compounds It is believed that cinnamon bark oil contains more than 70 phytochemicals comprising of: monoterpenes, oxygenated monoterpenes, sesquiterpenes, phenylpropanoids and benzenoids. The main components of the cinnamon bark extract are (E)-cinnamaldehyde, followed by (E)-cinnamyl alcohol, terpinen-4-ol, eugenol, linalool, (E)-cinnamyl acetate, o-pinene, limonene, 1,8-cineole, coumarin and β-caryophyllene [111]. On the other hand, *C. zeylanicum* bark water and ethanolic extracts can be sources of trimeric, and higher oligomeric proanthocyanidins, protocatechuic acid, as well as caffeic, chlorogenic and cinnamic acids. Additionally, it is a source of cinnamtannin B1, urolignoside, rutin, quercetin-3-rhamnopyranoside, kaempferol, procyanidin B1, apigenin and cinnamaldehyde. The last of these compounds is a highly electronegative phytochemical with many biological activities [103, 112, 113].

Health benefits The phytochemical constituents of *C. zeylanicum* may help with many different health problems. In folk medicine, it is used as a therapeutic agent against influenza, urinary tract inflammation, and as an antimicrobial agent. Aqueous extracts from the bark of *C. zeylanicum* can be responsible for the loss of weight, reducing blood glucose levels and LDL as well as increasing HDL cholesterol. It is known that cinnamon shows anti-inflammatory and antigastric activities, e.g. inhibiting gastric haemorrhagic lesions. In addition, the extract may show hepatoprotective effects. The extract also shows beneficial effects against neuropathy and nephropathy. Moreover, this extract also shows beneficial effects in Alzheimer's disease, inhibiting tau proteins aggregation and filament formation. What is more, it is believed that cinnamaldehyde extract can influence collagen biosynthesis regulating mRNA and type I collagen protein expression and thus may be useful in antiaging treatment [114].

Antimicrobial activity Both extracts and essential oils obtained from cinnamon are characterized by strong activity against broad spectrum of food poisoning microorganism, food spoilage microorganisms and human pathogens. Antibacterial activities of *C. zeylanicum* EOs have been documented against: *Acinetobacter* spp., *Clostridium perfringens, E. coli, K. pneumonia, P. aeruginosa, Salmonella typhi, B. subtilis, S. aureus, Streptococcus faecalis, S. pyogenes, Streptococcus agalactiae, S. pneumonia, Yersinia enterocolitica, Helicobacter pylori, Mycobacterium tuberculosis* and *Haemophilus influenza.* On the other hand, cinnamon extract shows inhibitory effect on *B. cereus, Bacillus coaguiaris, B. subtilis, P. aeruginosa, L. monocytogenes, Acinetobacter baumannii, E. cloacae, S. aureus, E. coli*, and food spoilage *A. lannensis* and *A. bogorensis*. What is more, essential oil of cinnamon shows antifungal activity against *Trichophyton* species (*Trichophyton mentagrophytes, T. tonsurans, T. rubrum*), *Microsporum* species (*M. canis, Microsporum gypseum, Microsporum audouinii*), *Candida* species (*C. albicans, Candida glabrata, C. parapsilosis, C. tropicalis*) as well as *Aspergillus* species (*A. fumigates, A. flavus, A. niger, A. terreus, A. ochraceus, A. nididans*) [103, 114–120].

4.8. Cloves (*S. aromaticum*)

Description Other aromatic spices popular all over the world are cloves (*S. aromaticum*), dried flower buds of clove tree belonging to the *Myrtaceae* family. The name of the spice comes from '*clavus*' which means nail. The clove tree is an evergreen tropical plant, native to Indonesia, but nowadays, the largest producer of cloves is Tanzania, then, Madagascar, Sri Lanka, Kenya, and the Seychelles. The dark colour of cloves is the result of its drying and fumigation, while the characteristic aroma is given by high concentration of eugenol. Due to the presence of essential oils in cloves, they have been used in India and China for over 2000 years and its oldest medicinal use was in China in around 240 BC [121].

Bioactive compounds *S. aromaticum* is characterized as one of the major plant sources of phenolic compounds, including flavonoids (kaempferol, quercetin and its derivatives), hydroxybenzoic acids and hydroxycinnamic acids (caffeic, gallic, ferulic, ellagic and salicylic acids and their derivatives such as hydrolyzable tannins). Essential oils in the clove flower buds are present in the concentration of 18%. Eugenol is the main bioactive compound of clove EOs and can be found in the concentration of 15 g per 100 g of the cloves. Simultaneously, the chemical compounds constitute 89% of the *S. aromaticum* EOs and are followed by eugenol acetate, β-*caryophyllene*, α-humulene, β-pinene, limonene, farnesol, benzaldehyde and 2-heptanone [122].

Health benefits Clove has been traditionally characterized as a medicinal plant with a wide range of pharmacological effects for centuries. Due to the high content of eugenol, oils and extracts are used as an antiviral agent, in the treatment of hiccups, and as antibacterial and antifungal agents. Since the thirteenth century, clove has been used as an analgesic agent. It was also reported that it may be used as an anaesthetic agent, acaricide and anticonvulsant. It is considered that the clove bioactive compounds possess great potential for pharmaceutical, cosmetic, food and agricultural applications [122]. It has been described that clove tea promotes the flow of saliva and gastric juices and can be used for stomach pain and gasses as well as for nausea and vomiting. Externally, EOs bring relief in muscle cramps, nerve conditions, chronic rheumatism, lumbago and toothache [123].

Antimicrobial activity Due to the characteristic aroma and antimicrobial activities, *S. aromaticum* can be used as a food flavouring and preservative. It has been documented that water extract shows bactericidal effect against food-borne pathogens such as *E. coli*, *S. aureus*, *B. cereus*, *L. monocytogenes*, *Listeria innocua and Salmonella enterica,* while eugenol from the cloves can inhibit the growth of *H. pylori* [124–126]. Clove oil is also described as an antifungal agent against: *Mucor* spp., *M. gypseum*, *M. canis*, *Fusarium moniliforme*, *T. rubrum*, *Aspergillus* strains, *Fusarium oxysporum* as well as against dermatophytes: *Trichophyton strains* (*T. mentagrophytes*, *T. rubrum*) [127, 128]. Therefore, clove extracts and essential oils show a great potential as food additives. They are a natural, effective antimicrobial agent and at the same time, give the food, a characteristic aroma which is preferred by the consumer.

4.9. Licorice (*G. glabra*)

Description Licorice is the root of *G. glabra* (*Leguminosae* family)—herbaceous perennial plant, growing up to 1 m high. The herb is generally native to southern Europe and parts of Asia, but nowadays, it can be found in India, Iran, Italy, Afghanistan, China, Pakistan, Iraq, Turkey as well as in England. The herb has been known in Chinese medicine and is believed to help to harmonize. Due to its medicinal properties and sweet taste, licorice has been used as a sweetening and flavouring agent in beverages, candies, tobacco and folk medicine [129].

Chemical composition *Glycyrrhiza* species has been documented as a source of 400 phytochemicals, from which triterpenoid saponins and flavonoids (licochalcone B, licochalcone A, echinatin, glycycoumarin and glyurallin B) are reported to be the main chemical compounds [129, 130]. The ethanolic extract of licorice root may contain genistein, glabrol, licochalcone C, as well as licorice glycoside A, licorice saponin A3 and glycyrrhizin [103] (**Figure 6**).

Health benefits Licorice has been reported as a source of biologically active phytochemicals. It is a well-known medicament in Chinese traditional medicine and is gaining popularity in other regions of the world. Licorice has been found to exhibit beneficial properties for the human organism. *Gracilimus radix* has been reported to possess antioxidative, antitumour (especially licochalcone A), antiviral, anti-inflammatory and immunity-stimulating properties. Glabridin, licoricidin and licorisoflavan A are mainly responsible for the anti-inflammatory and antioxidative activities. Moreover, glycyrrhizin from licorice has been shown to be responsible for the hepatic protective and antiulcer effects [131, 132].

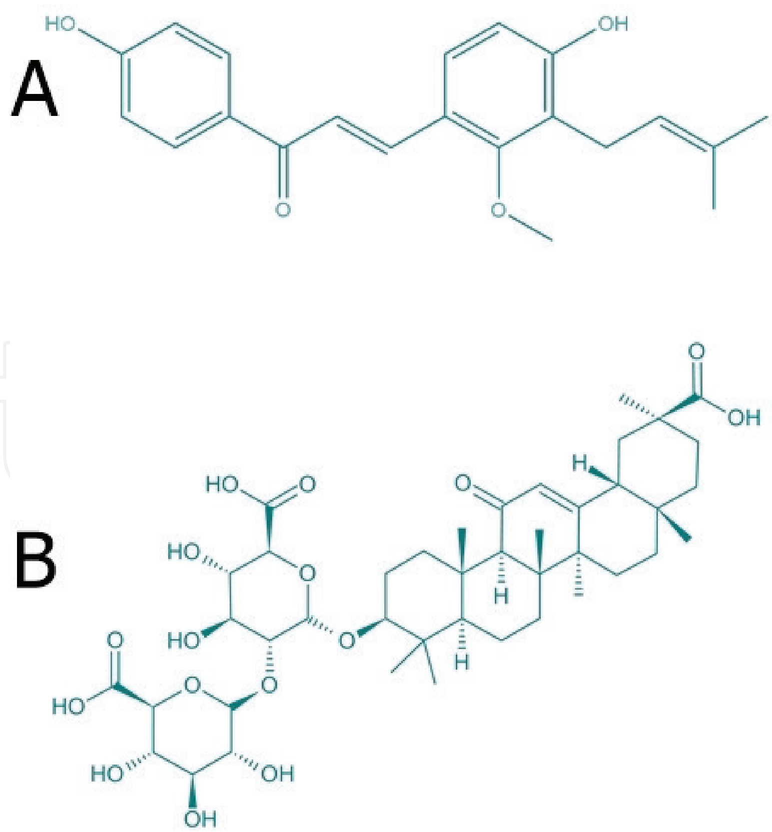

Figure 6. Chemical structure of licochalcone C (A) and glycyrrhizin (B).

Antimicrobial activity It has been noted that the extract of aerial parts of *G. glabra* exhibited antibacterial activity against *S. aureus*, *E. coli*, *B. subtilis*, *E. aerogenes* and *K. pneumoniae*. What is more, glabridin, glabrene and licochalcone A have been noted as antimicrobial compounds against *H. pylori*, while glycyrrhizol A showed antibacterial activity against *Streptococcus mutans* as well as *Mycobacteria* (*M. tuberculosis*, *Mycobacteria bovis*) species and *Legionella* (*Legionella pneumophila*, *Legionella bozemanii*, *Legionella dumoffii*, *Legionella longbeachae* and *Legionella wadsworthii*) species [133, 134]. What is more, probably due to the content of saponins, the extract from *G. glabra* showed antiadhesive activity against *A. lannensis* and *A. bogorensis* to food-packaging materials [103].

5. Fruit juices

In addition to essential nutrients, food also provides other health-promoting, bioactive compounds. It has been documented that a diet, and its certain components, plays a crucial role in the prevention of diseases and the treatment of others. A group of food products that is considered to be strongly associated and responsible for the reduction of the risk of cancer, diabetes, cardiovascular disease, ageing and many other are fruit. They are the major source of vitamins, micronutrients, macronutrients and secondary metabolites [135]. Secondary metabolites are a particularly important group demonstrating a broad spectrum of biological activities. Phenolic phytochemicals in plants are responsible for the protection against biological stresses in response to pathogenic attack and environmental conditions such as prolonged UV exposure [136]. There are numerous types of phytochemicals occurring in a relatively small amount in fruit. However, a group of secondary metabolites which have the health-promoting agents and are widespread in fruit are polyphenols, the most common of which are anthocyanins—responsible for red to blue and purple-black colours in fruit. Other health-benefiting compounds contained in fruit are tocopherols, glucosinolates, organosulphur compounds, sterols, stilbenes and tannins [137].

Particularly important, from the point of view of health-promoting properties and the possibility of use as additives (preservatives, colourings), are berries. They belong to the widespread family of fruits occurring in Europe, USA, Canada as well as countries of South America (Brazil, Colombia, Argentina, Paraguay and Uruguay). Main genera of berry fruits are *Vaccinium* spp.: *V. corymbosum* (blueberry), *V. myrtillus* (bilberry), *V. macrocarpon* (cranberry); *Fragaria* spp.: *F. virginiana* (strawberry); *Rubus*: *R. idaeus* (raspberry), *Rubus fruticosus* (blackberry), *Rubus ursinus* × *R. idaeus* (boysenberry); *Ribes* spp.: *Rubus rubrum* (red currant), *R. nigrum* (black currant); *Cornus* spp.: *C. mas* (cornelian cherry); *Aronia* spp.: *A. melanocarpa* (chokeberry), *Sambucus* spp.: *S. nigra* (elderberry). On the other hand, more tropical berries such as *E. oleracea* (açaí), *Eugenia uniflora* (pitanga), *Myrciaria cauliflora* (jabuticaba) and *Myrciaria dubia* (camu-camu) have also been known as the berries characterized by a high concentration of bioactive compounds [137, 138]. These fruits are rich in flavonoids (flavan-3-ols, flavonols, anthocyanins and procyanidins) and phenolic acids that possess antioxidant activities. Berries and their bioactive compounds generally reduce the incidence and mortality of cancer, cardiovascular diseases, and other diseases caused by oxidative stress, as well as coronary heart disease and cardiac stroke. The consumption of berries also results in amelioration of human ailments such as disorders in neuronal communication, inflammatory responses as well as improved memory in age [139]. Due to climate conditions, fresh berries can be consumed for several months. However, large portion of that is consumed in the form of juices, beverages, frozen products, wines and jams. What is more, due to the variety of bioactive compounds, which are characterized by beneficial activities on the health of consumers, antimicrobial properties as well as their characteristic colour, these fruits can certainly serve as a valuable additive to food products [140].

5.1. Cranberry (*V. macrocarpon*)

Description Cranberry or American cranberry (*V. macrocarpon* or *Oxycoccus macrocarpus*) belonging to the family *Ericaceae* is an evergreen dwarf shrubs native to North America and cultivated mainly throughout the northern United States and Canada. In Europe, cranberry may refer to *Vaccinium oxycoccos*, which is cultivated in central and north Europe. The fruits and leaves of the European cranberry are smaller and are refreshing, sharp and acidic in flavour, while American cranberry is slightly apple-like. The name 'cranberry' derives from 'craneberry' named by early European settlers in America, who compared small pink or red blossoms to head and bill of a 'crane'. The fruit are mainly consumed fresh, as concentrates, which have various value-added applications and juices [136, 141].

Bioactive compounds Cranberries have been recognized as a source of cyanidin-3-glucoside, cyanidin-3-galactoside, cyanidin-3-arabinoside, peonidin-3-glucoside, peonidin-3-galactoside, peonidin-3-arabinoside, delphinidin-3-glucoside, petunidin-3-glucoside and malvidin-3-glucoside, with a dominant concentration of peonidin-3-glucoside and cyanidin-3-glucoside. Among the phenolic acids, cranberry juice contains ellagic acid, ferulic acid, gallic acids, chlorogenic acids and neochlorogenic acids. Sour taste of fruit is caused by a high content of organic acids such as citric, malic and quinic. Cranberry also contains terpenes such as ursolic acid derivatives: cis-3-O-p-hydroxycinnamoyl ursolic acid and trans-3-O-p-hydroxycinnamoyl ursolic acid, as well as iridoid (monotropein) and coumaroyl iridoid glycosides. An analysis of the fractionation of cranberry juice guided by a bacterial antiadhesive assay revealed the presence of two new coumaroyl iridoid glycosides. What is more, these fruits are one of the sources of type A proanthocyanidin which is considered to be a bacterial antiadhesive agent [140, 141].

Health benefits Cranberries and cranberry products show various health-promoting properties. These berries are considered as one of the most popular and most effective natural treatments for urinary tract infections caused by uropathogenic strains of *E. coli*. It has also been described that phenolic acids and flavonoids from *V. macrocarpon* reduce oxidation of LDL, and thus the atherosclerotic process and cardiovascular disease. What is more, bioactive compounds from the juices of cranberry are able to modulate the induction of ODC (ornithine decarboxylase) and quinone reductase, which are responsible for tumour cell proliferation. Antitumor activity can also result from the inhibition of cancer cell proliferation. It is know that cranberry juice shows such activity against breast, prostate, lung, and leukaemia cells [136]. What is more, phenolic compounds from *V. macrocarpon* exhibit antiviral (against influenza A virus and type-1 herpes simplex virus), antimutagenic, antiangiogenic, anti-inflammatory and antioxidant activities [142].

Antimicrobial activity In addition to the antiadhesion properties of cranberry juice against uropathogenic strains of *E. coli*, the compounds contained in these fruits inhibit the attachment of *H. pylori* to human erythrocytes and human gastric mucous. Twenty-five percent of cranberry juice inhibited adsorption of oral pathogens *Streptococcus sobrinus* cells to saliva-coated hydroxyapatite beads in 10 seconds of contact time [143]. The proanthocyanidins from cranberry also showed inhibitory activity against gram-positive *S. epidermidis*, *S. aureus* and *Staphylococcus saprophyticus* [144]. It was documented that cranberry concentrate showed noticeable antimicrobial effect against *E. coli* O157:H7, *L. monocytogenes* and *S. typhimurium* [145]. Additionally, 10% cranberry juice decreased the adhesion of acetic acid bacteria *A. bogorensis* to food-packaging material [141]. Cranberry can also be an interesting candidate for natural preservation against fungal growth. Ermis et al. noted that a concentrate of cranberry juice can inhibit the growth of *Penicillium* spp., *Absidia glauca*, *Penicillium brevicompactum*, *Saccharomyces cerevisiae* and *Zygosaccharomyces bailii* [146]. It is believed that the juice can increase the microbiological safety of beverages and at the same time constitute as an alternative to the chemicals applied as food colourings.

5.2. Bilberry (*V. myrtillus*)

Description Bilberry (*V. myrtillus,* family *Ericaceae*) are Eurasian shrubs bearing small, nearly black berries. Bilberries are characteristic for North, East and Central Europe as well as Russia where they occur in forests. They are found in acidic, nutrient-poor soils, despite the fact that commercial cultivation is hard and berries are collected from natural environment. The name comes from Danish word 'bølle'. Despite the fact that the name is also used for a blueberry (*V. corymbosum*), there are a few differences between these two. Bilberries produce single or paired berries on the bush, while blueberries are gathered in clusters. Due to the significant amount of anthocyanins, *V. myrtillus* pulp is dark purple, even black, while the pulp of *V. corymbosum* is light green. What is more, shrubs of blueberry have more evergreen leaves [147].

Bioactive compounds The fruits of bilberries are one of the richest natural sources of anthocyanins, but they also contain flavanols, flavonols, phenolic acids and stilbenes. Among the anthocyanins commonly isolated from this material are: glucoside, galactosides and arabinosides of: delphinidin cyanidin petunidin peonidin and malvidin. Additionally, flavanol monomers (catechin, epicatechin), flavonols (quercetin, myricetin) as well as phenolic acids (chlorogenic, caffeic, ferulic, p-coumaric, ellagic, gallic acids) are detected. Bilberry triterpenoids consist of α- and β-amyrin, taraxasterol α-amyrenone and β-amyrenone, campesterol, citrostadienol, stigmasterol, sitostanol, cycloartenol and friedelin [148]. What is more, the presence of A type procyanidin trimer in the bilberry juice was also detected. The chemical composition of the bilberry fruits can be strongly dependent on the plant genotypes and environmental conditions [20, 147, 148].

Health benefits Due to the high content of anthocyanins, bilberries are considered to be one of the richest sources of antioxidants. *V. myrtillus* has been used in folk medicine since the

Middle Ages [148]. Fruits, juices and concentrates were all used as an antidiabetic, astringent and antiseptic agents as well as in a treatment for diarrhoea. Extracts of bilberry are documented as a source of bioactive compounds reducing illnesses such Parkinsonism, cancer and lungs diseases as well as Alzheimer's dementia [20, 149, 150]. In view of the improvement of elasticity and permeability of the capillary vessels of the eyeball, supplements with bilberry are used for the treatment of blood vessels disorders, thus improving microcirculation of the blood and vision. What is more, regular consumption may delay aging. It is also recognized that bilberries have a potential in the preventive management of type 2 diabetes, cardiovascular diseases, inflammation and hypertension [151].

Antimicrobial activity Bilberry phenolics have been reported to show antimicrobial effects against human pathogens, including *Salmonella* spp., *S. aureus*, *B. cereus* and *S. epidermidis*. Bioactive compounds from berries are generally able to inhibit *H. pylori*, *E. coli*, *Citrobacter freundii* and *Enterococcus faecalis.* Moreover, the phenolic compounds such as anthocyanins and flavonols can inhibit the growth of *Salmonella* spp. and *E.coli,* while tannins exhibit strong antimicrobial effect against *C. perfringens*, *Klebsiella* spp., and *Proteus* spp. [152–155]. Additionally, it has been shown that the juice of bilberry has a strong antiadhesive effect against gram-negative, beverage spoilage bacteria belonging to the genus *Asaia* [20].

5.3. Black currant (*R. nigrum*)

Description Black currant (*R. nigrum*) is a shrub in the family *Grossulariaceae* growing up to 2 m high in various parts of the world with temperate climate. *R. nigrum* is native to central and northern Europe and northern Asia, cultivated commercially and domestically. The plant can grow well on sandy and forest soils, as it does not tolerate both waterlogged grounds and droughts. Fruits, flowers, leaves bark and roots are strongly aromatic and have been used in traditional medicine. *R. nigrum* has been described as a garden plant in Russia in the eleventh century. It has been cultivated in Europe since the seventeenth century. It is worth mentioning that black currant shrubs were widely cultivated in the United Kingdom during World War II. Syrups obtained from the fruit were a source of vitamin C and were distributed free of charge to children under the age of two [156].

Bioactive compounds Berries of black currant contain many bioactive compounds showing benefits to the human health. Similar to the bilberry, *R. nigrum* are characterized by a high content of anthocyanins, which give them a strong purple colour. The source of the anthocyanins is the skin, containing: cyanidin-3-glucoside, cyanidin-3-rutinoside, delphinidin-3-glucoside and delphinidin-3-rutinosid, of which delphinidins are the main compounds. The main representative of the phenolic acids group are chlorogenic and neochlorogenic acids. Black currant fruits also contain: flavonols (myricetin and quercetin glycosides) as well as catechins (epigallocatechin, gallocatechin, epicatechin and epigallocatechin gallate) [156, 157].

Health benefits Black currant has recently been labelled as the so-called *super fruit* and is believed to possess several health benefits. Traditionally, juices and extracts of black currant fruits have been used as a protection against viral and bacterial infections. It was documented that it inhibited the influenza virus (IFV-A and IFV-B), the herpes simplex virus (HSV-1 and

HSV-2), inhibiting the protein synthesis of infected cells, as well as viruses associated with upper respiratory tract such as respiratory syncytial virus (RSV) and adenovirus (AdV). Bioactive compounds of the *R. nigrum* fruits show protective activities against neuronal damages. Anthocyanins decrease blood pressure, reduce muscle fatigue as well as enhance peripheral circulation. What is more, the juice shows strong activities against cancer cells proliferation [158]. It was described that consumption of *R. nigrum* can inhibit the growth of different cancer cells: Caco-2, human breast cancer cell lines (MDA-MB-231, MCF-7), human gastric carcinoma (AGS), human prostate cancer (PC-3) and human colon adenocarcinoma (HT-29). Moreover, *R. nigrum* extracts are rich in anthocyanin and exhibit antioxidant, anti-inflammatory and immunostimulatory properties [159, 160].

Antimicrobial activity Strong inhibition was observed in relation to *Serratia marcescens*, *B. subtilis*, *E. coli*, as well as *S. typhimurium*, *Campylobacter jejuni* and *Streptococcus pneumonie*—bacterium responsible for severe meningitis and pneumonia in infants [153, 161–163]. It is considered that blackcurrant juices are generally more efficient against gram-positive than against gram-negative bacteria. Anticandidal activity against *C. albicans*, *Caesalpinia pulcherrima*, *C. krusei* and *C. lusitaniae* was also observed [164]. In addition to growth inhibition, the juice of black currant possesses anti-adhesive activity against *Asaia* species [20]. Black currant extracts show inhibition of microbial growth and adsorption and can be easily used as a natural preservative in food products.

5.4. Elderberry (*S. nigra*)

Description Elderberry (*S. nigra*) is a shrub reaching up to 6 m high belonging to the *Adoxaceae* family. The plant is native to sunlight-exposed areas of Asia, Africa, North America and Europe [104]. It is believed that early settlers brought elderberry seeds from Europe (*S. nigra*) and the plant became naturalized in North America (*Sambucus canadensis*). The name *Sambucus* probably derives from the Greek '*sambuke*' or the Latin '*sambuca*', referring to a kind of flute which has been made out of twigs. In the beginning, elder berries are oblong, compact and green, and after 6–8 weeks, they gradually enlarge and change colour from red to purple and black. Ripe fruits may range from 5 to 7 mm in diameter, weighing approximately 50–130 mg [165].

Bioactive compounds Similar to other dark berries, anthocyanins are mainly responsible for the colour of the elderberry. In addition, they contain flavonols, phenolic acids and proanthocyanidins. *S. nigrum* anthocyanins are cyanidin derivatives (e.g. cyanidin-3-sambubioside-5-glucoside), pelargonidin derivatives (pelargonidin-3-sambubioside) and delphinidin derivatives (delfinidine-3-rutinoside). Due to the presence of acylated form of anthocyanins, American elderberries show greater diversity in the composition. Elderberry fruits are also one of the richest sources of phenolic acids: chlorogenic, crypto-chlorogenic, neochlorogenic acids and ellagic acid, but their content is less diverse than in those of the flowers of elderberry. Among flavonols, the fruits contain quercetin, kaempferol and isorhamnetin as well as their glycosylated forms (rutin and glucose). Proanthocyanidins occur in elderberries in a relatively small concentration, few times lower than in chokeberry and black currant [107].

Health benefits The use of elderberry fruits as well as other parts of the plant: flowers, leaves, roots and bark has been known since ages. The first report mentioning the use of the elderberry, *De Materia Medica* comes from Ancient Rome. In American and European cultures, *Sambucus* spp. has been used in folk medicine in treating respiratory diseases (influenza, colds and catarrh), and as a diaphoretic, diuretic, laxative and anti-inflammatory, natural bioactive agent. It has also been used for swelling, haemorrhoids, rheumatic symptoms, toothaches, kidney and eye problems, as well as in hepatitis and dyspepsia. What is more, the *S. nigrum* extracts can exhibit immunostimulatory activities (by the stimulation of the production of IL-1β, IL-6, IL-8 and IL-10 as well as TNF-α), is responsible for the reduction of glycaemia and may reduce blood pressure [107]. However, the fruits are most known for their antiviral activity, including against the H1N1 virus [166].

Antimicrobial activity Antimicrobial properties of extracts from different parts of elderberry (*S. nigrum*) have been documented against *B. cereus*, *Serratia marcescens*, *E. coli*, *S. aureus*, *P. aeruginosa Salmonella* spp. as well as *B. subtilis*, *B. megaterium*, and yeasts: *D. hansenii*, *Z. rouxii*, *Rhodotorula rubra*, *Candida shehatae* and *C. tropicalis* [107, 109]. Commercially standardized extracts of elderberry such as 'Rubini' showed antimicrobial activities against human pathogens: *S. pyogenes* and *Branhamella catarrhalis* [167]. Extract from elderberry showed inhibitory effect of the growth of *Mycoplasma mycoides* subsp*. capri*, *E. coli*, *B. subtilis* [168], and clinical strains of *H. pylori* [169].

5.5. Cornelian cherry (*C. mas*)

Description The cornelian cherry (*C. mas*, family *Cornaceae*) is considered to be a high deciduous shrub or a small tree growing from 5 to 8 m. The cornelian cherry is a rare plant occurring in Europe (Belgium, Germany, the Czech Republic, Slovakia, UK as well as Turkey which is the main producer of these fruits). The plant is characterized by its extraordinary tolerance to environmental conditions. There is a saying 'healthy as the Cornelian cherry'. The fruits are long, cherry-like with sour taste [170].

Bioactive compounds *C. mas* is particularly rich in ascorbic acids and anthocyanins such as delphinidin galactopyranoside, delphinidin rutinoside, delphinidin glucoside, cyanidin glucoside, cyanidin rutinoside, cyanidin galactopyranoside, pelargonidin galactopyranoside and pelargonidin-3-glucoside. What is more, phenolic acids (gallic, ellagic, chlorogenic), as well as (+)-catechin, (-)-epicatechin, procyanidin B2, luteolin-3-glucoside, kaempferol-3-glucoside occur as the bioactive composition of the *C. mas* fruits [170–172].

Health benefits Fresh fruits of Cornelian cherry from Greece are characterized by one of the strongest antioxidant activities compared to other fruit from this region. Further, *C. mas* are known as a source of phytochemicals showing antihistamine, antiallergic, antimalarial as well as antidiabetic potential. They have also been used as a source of bioactive compounds showing beneficial effect on liver and kidney. In Asian countries, cornelian cherry has been used as an antidiabetic agent. The high level of antioxidants in these fruits makes them a candidate for the prevention or treatment of neurological diseases [172–174].

Antimicrobial activity Extracts from fresh *C. mas* fruits have been shown to possess strong antibacterial activity against both gram-positive and gram-negative bacteria: *S. aureus* and *P. aeruginosa* [175]. Wide spectrum of antibacterial and anticandidal activities of both juice of *C. mas* and extract of their leaves has been documented in the article of Milenković-Andjelković et al. The author noted inhibition in growth of: *C. perfringens*, *B. cereus*, *S. aureus*, *L. monocytogenes*, *Sarcina lutea*, *M. flavus*, *E. coli*, *P. aeruginosa*, *Salmonella enteritidis*, *Shigella sonnei*, *K. pneumoniae*, *P. vulgaris* as well as *C. albicans* [171]. However, further antimicrobial properties of this plant are being studied and raising great interest as an additive to food products.

5.6. Açaí (*E. oleracea*)

Description Açaí (*Euterpe oleracia)* is a species of palm tree belonging to the family *Arecaceae*, cultivated in South America, the Amazonian flood lands, Brazil and Columbia. In recent years, an increasing demand for both the heart of the palm trees, as well as its fruits has been observed. The trees are tall, reaching over 25 m. The fruits are purple black, about 10 mm in diameter, with flavour similar to raspberries. Visually, they are similar to grapes, but they are much smaller and are produced in branched panicles of 900 fruits. Due to the low sugar value, the fruits are not sweet but contain a high amount of dietary fibres [137].

Bioactive compounds It is recognized that these fruits are one of the richest and most diverse sources of bioactive compounds. Among the anthocyanins, açaí berries contain cyanidin-3-glucoside, cyanidin-3-rutinoside, cyanidin-3-acetylhexose, cyanidin-3-arabinoside, cyanidin-3-sambubioside, peonidin-3-rutinoside, peonidin-3-glucoside and pelargonidin-3-glucoside. In addition, they also contain flavonoids: apigenin diglucoside, homoorientin, orientin, taxifolin deoxyhexose, taxifolin-3-rhamnoside, isovitexin, velutin, scoparin, as well as catechin and epicatechin. Additionally, the presence of procyanidin dimers and trimers was also noted. An important part of the phenolic components in the fruits is phenolic acids: protocatechuic, p-hydroxybenzoic, vanillic, syringic, ferulic, gallic, benzoic, p-coumaric and ellagic. It is hardly surprising that *E. oleracea* fruits are considered to be one of the most important sources of health benefiting phytochemicals and recognized as '*super food*' [137].

Health benefits Due to the richness in bioactive compounds, they are a promising health-benefiting food product or food additive. It is believed that açaí could play an important role in the prevention of cancer, cardiovascular diseases show antioxidant action in relation to human endothelial cells and show effects on epigenetics modulators, such as microRNAs. The juice when drunk regularly can have positive effects on blood lipid levels and can protect the heart from coronary heart disease, as well as reduce probability of type 2 diabetes. Further, it was noted that the extract of *E. oleracea* is responsible for the reduction of total cholesterol levels and can be helpful in weight reduction and maintaining healthy weight. Due to the high phenolic content and dietary fibres, these fruits can be used in the treatment of digestive problems. Additionally, regular consumption of *E. oleracea* can result in increased focus and memory improvement, as well as protect against the damaging effects of stress, and thus, it is considered to be an '*adaptogen*' [131]. Therefore, it is considered to commercialize the juice from these berries as an additive to different food products, for example beverages [176].

Antimicrobial activity Despite the fact that the berries have long been used in folk medicine as therapeutic agents that contain one of the highest concentrations of bioactive compounds, the data on its antimicrobial activities are very limited. However, the similarity in the composition of phytochemicals to other berry fruits allows us to assume that açaí may show such activity [137, 176].

6. Conclusion

Microbial food safety is a constant, global problem affecting the health of consumers. Due to the increasing resistance of microorganisms to chemicals used for the technological lines disinfection, as well as lower sensitivity to the synthetic preservatives, alternative sources of natural, bioactive, and antimicrobial compounds are needed. The information presented in our chapter shows that certain fruit, herbs and spices as well as phytochemicals, and their mixtures are characterized by strong antimicrobial and antiadhesive activities against food-borne pathogens, food spoilage bacteria, yeasts and moulds, as well as against human pathogens. Simultaneously, they have health-promoting properties and show therapeutic and preventative effects. Furthermore, from the technological point of view, essential oils, plant extracts and fruit juices may be used in food products as other additives than preservatives. Due to the essential oil content, they may be used as flavourings, while a high level of anthocyanins in berries makes them an ideal candidates to be colouring agents. There is no doubt that these natural products can be used in food production, helping to maintain stability of the products and meeting the demands of consumers in relation to natural food additives.

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