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Bioactive Compounds and Health-Promoting Properties of Berry Fruits: A Review

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Abstract This study characterizes biologically active compounds of berry fruits, including non-nutritive compounds such as phenolic compounds, including anthocyanins, phenolic acids, stilbens and tannins, as well as nutritive compounds such as carotenoids and vitamin C. It discusses the biological activity of those compounds, in particular their antioxidant properties and the resulting health benefits.

Keywords Antioxidant activity · Berry fruits · Biological activity · Biologically active compounds · Medicinal properties

Introduction

Numerous epidemiological studies conducted in many countries indicate that a diet rich in fruits and vegetables, including fruit and vegetable products, delays the ageing process and reduces the risk of various lifestyle diseases, mainly cardiovascular diseases and cancer, as well as other disorders, such as rheumatoid arthritis, lung diseases, cataract, Parkinson's or Alzheimer's disease [1–8]. It is believed that the compounds which are largely responsible for those protective effect are phytochemicals and vitamin C and E which have antioxidant properties. Their activity is manifested by the scavenging ability of reactive oxygen species (ROS), such as hydroxyl, peroxide radicals and radicals of other reactive forms of oxygen, including hydrogen peroxide and singlet oxygen. The discussed compounds inhibit the activity of enzymes and form complexes with metals which catalyze oxidation reactions [9–11]. The indicated properties of fruit and vegetable compounds determine their health-promoting properties.

Berry fruits, such as bilberry (*Vaccinium myrtillus*), blackberry (*Rubus fruticosus*), blackcurrant (*Ribes nigrum*), blueberry (*Vaccinium corymbosum*), chokeberry (*Aronia melanocarpa*), cranberry (*Vaccinium macrocarpon*), grape (*Vitis vinifera*), raspberry (*Rubus idaeus*) and strawberry (*Fragaria x ananassa*) are a particularly rich source of antioxidants [12–18]. Those compounds are mainly represented by vitamin C and polyphenols such as anthocyanins, phenolic acids, flavanols, flavonols and tannins. They are known as natural antioxidants and due to their high concentration and qualitative diversity, berry fruits are increasingly often referred to as natural functional foods. These findings have been confirmed in the research of Häkkinen and Törrönen [19], Wang and Lin [20], Connor et al. [21], Hakala et al. [22], Skupień and Oszmiański [23], Taruscio et al. [24]. As demonstrated by clinical research, the bioavailability of those naturally occurring compounds significantly exceeds the health benefits carried by their corresponding supplements in pharmaceutical form [16, 25, 26]. Due to climatic conditions, fresh berry fruits are generally available for consumption several months a year, while some of the harvested fruit is processed to juice, fruit beverages, frozen products, wine, jam, marmalade and jelly [12, 27–32].

This paper discussed the key bioactive compounds of berry fruits and their health-promoting properties to emphasize the importance of berry fruits in the diet and in the prevention of various diseases.

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Phenolic Compounds

Berry fruits are characterized by a high content and wide diversity of phenolic compounds. They differ with regard to structure and molecular weight and are represented by phenolic acids (benzoic and cinnamic acid derivatives), tannins, stilbenes and flavonoids such as anthocyanins, flavonols and flavanols (catechins) [33–35]. Their concentration is usually higher in the epidermis and in the tissue directly beneath than in the central part of the fruit.

The content of phenolic compounds in berry fruits is determined by many factors, such as the species, variety, cultivation, region, weather conditions, ripeness, harvesting time, storage time and conditions [18, 19, 21–23, 36–41]. Phenolic compounds are the secondary metabolites of plant, and are needed to normal their growth and development. They protect the species against adverse factors which threaten its survival in a unfavourable environment, such as drought, UV radiation, infections or physical damage [18, 42–43]. A prime example of the above is resveratrol, a substance found in the skin of grapes which inhibits the growth of fungi [33]. As demonstrated by Scandinavian research [14, 19], the level of phytochemicals is largely determined by environmental conditions. Researchers have shown that the fruits of berry plants which grow in a cold northern climate with a short vegetation season, without fertilizers and pesticides are marked by a higher content of polyphenols than the same varieties which grow in a milder climate. In addition to protective functions, phenolic compounds—in particular anthocyanins—are responsible for the pigmentation of flowers, fruit and leaves [33, 44].

Until recently, phenolic compounds were regarded as non-nutritive compounds of fruits and vegetables which often hinder their technological processing. Those compounds are responsible for the presence of sediment and haze in juice [45]. An excessive content of polyphenols, in particular tannins, may have adverse consequences because it inhibits the bioavailability of iron [46, 47] and thiamine [48] and blocks digestive enzymes in the gastrointestinal tract [33, 49]. Phenolic compounds can also limit the bioavailability of proteins with which they form insoluble complexes in the gastrointestinal tract [33, 50]. Moreover, interactions between tannins and proteins lead to astringency [33, 51]. The views on the significance of phenolic compounds were gradually modified in the nineties, and today they are recognized as a component which may possess certain problems during processing but, nevertheless, offers many health benefits and are vital in nutrition [4, 6, 33, 52, 53].

The phenolic compound content of selected berry fruit species is presented in Table 1. A particularly high content was reported in chokeberry, bilberry and blackcurrant [14, 17, 44, 57].

Table 1 Total phenolic content of berry fruits

Species	Phenolics (mg/100 g fresh weight)	References
Bilberry	525.0	[54]
(Vaccinium myrtillus)		
Blackberry	361	[55]
(Rubus fruticosus)	417–555	[16]
Blackcurrant	318.15	[17]
(Ribes nigrum)	498–1342	[15]
Blueberry	181.1–473	[54]
(Vaccinium corymbosum)	261–585	[16]
Ckokeberry	662.5	[17]
(Aronia melanocarpa)	690.2	[18]
Cranberry	120.0–176.5	[56]
(Vaccinium macrocarpon)	315	[57]
Raspberry	113.73–177.6	[28]
(Rubus idaeus)	192–359	[39]
	517	[58]
	330	[59]
Strawberry	317.2–443.4	[23]
(Fragaria x ananassa)	102	[60]

Anthocyanins

Anthocyanins occupy a special place in the group of polyphenols found in berry fruits. A high concentration of anthocyanins is reported in chokeberry, bilberry, honeyberry, blackcurrant, grapes and blackberry [17, 18, 30, 33]. The total content of anthocyanins in selected berry fruit species is presented in Table 2.

Anthocyanins in berry fruits comprise a large group of water-soluble pigments. In fruit, they are found mainly in the external layers of the hypodermis (the skin). In cells, they are present in vacuoles in the form of various sized granules, while cell walls and flesh tissue contain practically no anthocyanins. All tissues are subject to dye only after mechanical or thermal damage to the cellular structure. Anthocyanins comprise aglycones—anthocyanidins and their glycosides—anthocyanins [33]. They form a highly differentiated group of compounds. Anthocyanins differ with regard to the number of hydroxyl groups in a molecule, the degree of methylation of these groups, the type, number and place of attachment of sugar molecules, and the type and number of aliphatic or aromatic acids attached to sugars in an anthocyanin molecule [11, 64]. In berry fruits, anthocyanins are found in the form of mono-, di- or triglycosides, where glycoside residues are usually substituted at C3 or less frequently, at C5 or C7. The most prevalent sugars are glucose, galactose, rhamnose, arabinose, rutinose, sambubiose, and sophorose. [33, 65] Anthocyanin glycoside residues are often acylated by acids: *p*-coumaric acid, caffeic acid, ferulic acid, and—less frequently—by *p*-hydroxybenzoic acid, malonic acid or acetic acid [33].

Table 2 Anthocyanin content of berry fruits

Species	Anthocyanins (mg/100 g fresh weight)	References
Bilberry	299.6	[54]
(Vaccinium myrtillus)	214.7	[17]
Blackberry	134.6–152.2	[61]
(Rubus fruticosus)		
Blackcurrant	128–411	[15]
(Ribes nigrum)		
Blueberry	62.6–235.4	[54]
(Vaccinium corymbosum)	89–331	[62]
	93–280	[21]
Chokeberry	311.02	[17]
(Aronia melanocarpa)	428	[57]
	460.5	[18]
Cranberry	19.8–65.6	[56]
(Vaccinium macrocarpon)	32	[57]
Raspberry	38.7	[37]
(Rubus idaeus)	65	[58]
	19–51	[39]
	35.1–49.1	[61]
Redcurrant	7.5–7.8	[61]
(Ribes rubrum)		
Strawberry	39.08	[63]
(Fragaria x ananassa)	20.07	[60]

Both the content of anthocyanins and their qualitative composition in berry fruits are determined by the species of the fruits (Table 3). The composition of anthocyanins is particularly diversified in the fruit of blueberry and bilberry where more than ten anthocyanins have been found [66, 67, 71, 72]. Less distinctive qualitative differences are observed in the fruit of chokeberry, strawberry and raspberry [59, 73, 76].

Phenolic Acids

Phenolic acids in berry fruits are represented by cinnamic acid and benzoic acid derivatives [34, 78]. They occur mainly in bound forms as esters or glycosides [33, 78]. From among benzoic acid derivatives, *p*-hydroxybenzoic acid, salicylic acid, gallic acid and ellagic acid were found in berry fruits, and in the group of cinnamic acid derivatives—the presence of *p*-coumaric acid, caffeic acid and ferulic acid was determined [19, 23, 24, 78]. In the group of hydroxycinnamic acids, the highest quantity of caffeic acid derivatives—chlorogenic acids (esters of caffeic acid and quinic acid)—was reported. Chlorogenic acids are responsible for the tart taste of fruit and fruit products, and in the presence of polyphenol oxidase they are easily oxidized and further transformed into brown-colored compounds [33]. Chokeberry is a rich source of hydroxycinnamic acid derivatives [33]. They are represented mainly by caffeic acid derivatives—chlorogenic acid and neochlorogenic acid. In chokeberry fruit, the content of those acids reaches 301.85 mg/100 g dried weight and 290.81 mg/100 g dried weight, respectively [79]. The presence of those acids in fruit was confirmed by the findings of Slimestad et al. [74]. Ellagic acid is the dominant acid in strawberries where it accounts for 51% of all acids found in this species [19, 23, 29]. It is present in free form or is esterified to glucose in hydrolysable ellagitannins [80]. The total content of ellagic acid determined after acid hydrolysis ranges from 25.01 to 56.35 mg/100 g fresh weight [23]. According to Häkkinen et al. [36], ellagic acid is also the predominant phenolic acid in raspberries where it accounts for 88% of all phenolic acids. Large quantities of ferulic acid were found in cranberry and blueberry, significant amounts of *p*-coumaric acid and ferulic acid were reported in bilberry, while blackcurrant was marked for its high content of *p*-coumaric acid and caffeic acid [36].

Tannins

Tannins are an important component of berry fruits. They comprise both condensed non-hydrolysable tannins, known as proanthocyanidins, and esters of gallic acid and ellagic acid—defined as hydrolysable tannins [33, 34]. Tannins play an essential role in shaping the sensory properties of fruit and fruit products. They are responsible for the tart taste and changes in the color of fruit and fruit juice. The tart taste results from the interactions between tannins and the proteins of mucous membranes and gustatory receptors. As enzyme inhibitors, tannins decrease the nutritive value of some plant products [33, 49, 51]. In fruit rich in anthocyanins, tannins stabilize anthocyanins by binding to them to form copolymers [33, 81]. Most fruits contain condensed tannins. Hydrolysable tannins (derivatives of gallic and ellagic) are less frequently encountered and have been found in strawberries, raspberries and blackberries [82]. In berry fruits, the largest quantity of condensed tannins with a high degree of polymerization is found in chokeberry [79]. Small quantities of tannins were found in honeyberry and blackberry. According to Foo and Porter [82], blackberry contains only hydrolysable tannins. Oszmiański and Wojdylo [79] employed the thiolysis method to determine the presence of condensed tannins in chokeberry fruits. Fruit tannins comprise (−)epicatechin and (+)catechin. (−)Epicatechin is the dominant tannin component in chokeberry.

Stilbenes

This group of compounds includes resveratrol which was initially found in grapes. It occurs as free resveratrol and as piceid, i.e. 3-β-mono-D-glucoside [83]. Small quantities of *trans*-resveratrol were also found in bilberry, cowberry,

Table 3 Anthocyanin profile in berry fruits

Species	Anthocyanin profile	Anthocyanins dominant	References
Bilberry *(Vaccinium myrtillus)*	Delphinidin-3-galactoside, delphinidin-3-glucoside, cyanidin-3-galactoside, delphinidin-3-arabinoside, cyanidin-3-glucoside, cyanidin-3-arabinoside, petunidin-3-glucoside, petunidin-3-galactoside, peonidin-3-galactoside, petunidin-3-arabinoside, peonidin-3-glucoside, malvidin-3-galactoside, malvidin-3-glucoside, malvidin-3-arabinoside, delphinidin-3-sambubioside, cyanidin-3-sambubioside	Malvidin-3-glucoside, cyanidin-3-glucoside, delphinidin-3-galactoside, cyanidin-3-galactoside	[66, 67]
Blackcurrant *(Ribes nigrum)*	Cyanidin-3-glucoside, cyanidin-3-rutinoside, delphinidin-3-glucoside, delphinidin-3-rutinoside, peonidin-3-rutinoside, malvidin-3-rutinoside	Delphinidin-3-rutinoside	[68-70]
Blackberry *(Rubus fruticosus)*	Cyanidin-3-galactoside, cyanidin-3-glucoside, cyanidin-3-arabinoside, pelargonidin-3-glucoside, cyanidin-3-xyloside, malvidin-3-glucoside	Cyanidin-3-glucoside	[66, 68]
Blueberry *(Vaccinium corymbosum)*	Delphinidin-3-galactoside, malvidin-3-galactoside, malvidin-3-glucoside, malvidin-3-arabinoside, delphinidin-3-arabinoside	Malvidin-3-arabinoside, malvidin-3-glucoside, malvidin-3-galactoside	[71, 72]
Chokeberry *(Aronia melanocarpa)*	Cyanidin-3-galactoside, cyanidin-3-glucoside, cyanidin-3-arabinoside, cyanidin-3-xyloside	Cyanidin-3-galactoside	[73, 74]
Cranberry *(Vaccinium oxycoccus)*	Cyanidin-3-glucoside, cyanidin-3-galactoside, cyanidin-3-arabinoside, peonidin-3-glucoside, peonidin-3-galactoside, peonidin-3-arabinoside, delphinidin-3-glucoside, petunidin-3-glucoside, malvidin-3-glucoside	Peonidin-3-glucoside, cyanidin-3-glucoside	[75]
Raspberry *(Rubus idaeus)*	Cyanidin-3-sophoroside, cyanidin-3-glucoside, cyanidin-3-glucorutinoside, cyanidin-3-rutinoside, pelargonidin-3-sophoroside, pelargonidin-3-glucoside	Cyanidin-3-sophoroside	[59, 76]
Strawberry *(Fragaria x ananassa)*	Pelargonidin-3-glucoside, cyanidin-3-glucoside, pelargonidin-3-arabinoside, pelargonidin-3-sukcynyloglucoside, cyanidin-3-sukcynyloglucoside	Pelargonidin-3-glucoside	[23, 59, 77]

redcurrant, cranberry and strawberry [40, 83–85]. The content of *trans*-resveratrol in the fresh weight of the above fruit reaches 6.78 µg/g, 30.00 µg/g, 15.72 µg/g, 19.29 µg/g and 3.57 µg/g respectively [40].

Carotenoids

Berry fruits contain small quantities of carotenoids [86–89]. Chokeberry is one of the richest sources of carotenoids whose content reaches 48.6 mg/kg fresh weight on average. Chokeberry fruits contain lycopene, β-carotene, ζ-carotene, β-cryptoxanthin, lutein, 5,6-epoxylutein, *trans*-violaxanthin, *cis*-violaxanthin and neoxanthin [87].

Vitamin C

Ascorbic acid is one of important water-soluble vitamins. It is widely distributed in fresh fruits and vegetables. Most plants and animals synthesize ascorbic acid from D-glucose or D-galactose. However, humans cannot synthesize ascorbic acid due to the absence of the enzyme L-gulonolactone oxidase. L-ascorbic acid is the trivial name of vitamin C. The chemical name is 2-oxo-L-threo-hexono-1,4-lactone-2,3-enediol. L-ascorbic acid and dehydroascorbic acid are the major dietary forms of vitamin C [90].

Similarly to phenolic compounds, the content of vitamin C in berry fruits is determined by numerous factors, including species, variety, cultivation, climate, weather conditions, ripeness, region, storage time and conditions [22, 23, 37, 38, 54, 61, 91]. Blackcurrant fruits are the richest source of vitamin C among all berry fruit species. A relatively high vitamin C content is also reported in strawberries [18, 22, 91]. The vitamin C content of selected fruit species is presented in Table 4.

Antioxidant Properties of Berry Fruits

Berry fruits owe their antioxidant properties mainly to phenolic compounds, including phenolic acids, tannins,

Table 4 Vitamin C content of berry fruits

Species	Vitamin C (mg/100 g fresh weight)	References
Blackberry *(Rubus fruticosus)*	15.5–16.3	[18]
Blackcurrant *(Ribes nigrum)*	125.2–151.1	[91]
Blueberry *(Vaccinium corymbosum)*	12.4–13.1	[18]
Chokeberry *(Aronia melanocarpa)*	13.1	[18]
Raspberry	22.07–31.09	[28]
(Rubus idaeus)	15.4–32.0	[38]
	26	[59]
Redcurrant *(Ribes rubrum)*	17–21	[91]
Strawberry	29–48	[91]
(Fragaria x ananassa)	32.4–84.7	[22]
	23.8–51.0	[18]

stilbenes and flavonoids which are represented by anthocyanins, flavonols and flavanols. The antioxidant activity is determined by the species, variety, cultivation, region, weather conditions, ripeness, harvesting time, storage time and conditions [18, 23, 33, 37, 56, 57, 92]. The antioxidant capacity of selected berry fruit species is presented in Table 5.

The fruits of chokeberry, bilberry and blackcurrant are marked by particularly high antioxidant capacity [17, 18, 54, 57]. Those species have the ability to scavenge DPPH$^{\bullet}$, ABTS$^{\bullet+}$ and OH$^{\bullet}$ radicals, superoxide radicals and other reactive forms of oxygen, such as hydrogen peroxide and singlet oxygen [17, 20, 23, 24, 62, 94, 95], they inhibit the oxidation of LDL [55, 96–98], liposomes [55] and prevent the formation of NO$^{\bullet}$ radicals [99]. Phenolic compounds extracts from fruit are characterized by higher antioxidant activity than many pure phenolic compounds or vitamins [100] which could point to the mutual synergistic effect of antioxidants. According to Liao and Yin [101], and Vinson et al. [100], the protective effect of ascorbic acid and α-tocopherol over lipoproteins increases when catechin, epicatechin or caffeic acid is added. According to clinical research, the bioavailability of natural antioxidants exceeds that of the corresponding pharmaceutical supplements as regards their health benefits. No mixture of biologically active substances, which have recently gained widespread popularity in the form of—for example—functional beverages, is able to replace the naturally occurring compounds in fresh fruit or juice (in particular hazy juice) [26, 53].

Table 5 Antioxidant capacity of berry fruits (ORAC method)

Species	Antioxidant capacity (μmol Trolox/g fresh weight)	References
Bilberry *(Vaccinium myrtillus)*	44.6	[54]
Blackberry *(Rubus fruticosus)*	14.8–22.6	[93]
Blackcurrant *(Ribes nigrum)*	36.9–93.1	[15]
Blueberry	16.8–42.3	[54]
(Vaccinium corymbosum)	4.6–30.5	[62]
Chokeberry *(Aronia melanocarpa)*	160.2	[57]
Cranberry	8.2–14.1	[56]
(Vaccinium macrocarpon)	18.5	[57]
Grape *(Vitis vinifera)*	7.39	[26]
Raspberry *(Rubus idaeus)*	18.49	[59]
Strawberry	15.36	[26]
(Fragaria x ananassa)	24.37	[59]

Compounds occurring in berry fruits are marked by varied antioxidant activity. The TEAC values obtained by Rice-Evans et al. [102] for phenolic compounds were three- to fivefold higher than for ascorbic acid. According to the findings of Wang et al. [26], the activity of ascorbic acid is similar to Trolox, while the activity of some polyphenols is several times higher than the above reference standard. For example, cyanidin is 4.4 times more active than ascorbic acid, quercetin—4.7 times more active, and tannins—3 to 30 times more active.

The antioxidant activity of the compounds found in berry fruits relies on various mechanisms, subject to their structure [11, 103–105]. It is believed that phenolic compounds protect the easily oxidizable food compounds. They inhibit the oxidation of vitamin C, carotenoids and unsaturated fatty acids [33]. Flavonoids inhibit lipid oxidation, they chelate metals and scavenge the active forms of oxygen [11]. Anthocyanins—which are a flavonoid subgroup—inhibit the oxidation of human LDL and liposomes, and scavenge free radicals [104, 106, 107]. They protect ascorbic acid against oxidation [108]. In the group of phenolic acids, cinnamic acid derivatives, such as caffeic acid, chlorogenic acid, ferulic acid, sinapic acid and *p*-coumaric acid are more active antioxidants than benzoic acid derivatives, such as *p*-hydroxybenzoic acid and vanilic acid [57]. Meyer et al. [98] demonstrated that hydroxycinnamic acids are capable of inhibiting LDL oxidation *in vitro*. In the group of phenolic compounds, tannins are characterized by particularly high antioxidant properties [109]. Ellagic acid derivatives and condensed tannins have a much greater free radical scavenging ability than ascorbic acid, tocopherols and low-molecular weight polyphenols. Porter et al. [110] demonstrated that proanthocyanidin found in cranberry inhibits the oxidation of human LDL catalyzed by copper ions *in vitro*.

Vitamin C inhibits the initiation and disrupts the oxidation process, thus protecting the LDL fraction. Until recently, it was assumed that ascorbate is the only effective antioxidant. The latest research, however, has demonstrated that LDL fractions can be effectively protected against oxidation by both ascorbate and dehydroascorbate. It was found that both forms of vitamin C delay the initiation of the process of LDL fraction oxidation induced by Cu^{2+} ions [111]. Ascorbic acid neutralizes a number of free radicals and atomic oxygen in an aqueous environment. It is involved in the process of detoxification of air pollutants, such as ozone, NO_2 and free radicals of cigarette smoke [112]. Due to the high concentration of polyphenols in berry fruits, the proportion of vitamin C in the total antioxidant activity of these species is relatively low [26, 37]. According to Wang et al. [26], the share of vitamin C in total antioxidant activity measured by the ORAC method does not exceed 15%.

Carotenoids scavenge free oxygen radicals and fatty acid peroxides produced in the process of lipid oxidation. Carotenoids have the ability to scavenge the active forms of oxygen, thus preventing the oxidation of low-density lipoproteins [113, 114].

The results of many studies point to correlations between the total content of phenolic compounds and anthocyanins in berry fruits, and their antioxidant activity. These findings are supported by, among others, Wang et al. [26], Kalt et al. [13], Wang and Lin [20], Ehlenfeldt and Prior [62], Wada and Ou [58], Gonzalez et al. [115], Taruscio et al. [24] and Cho et al. [116]. Those authors have demonstrated that antioxidant activity is more strongly correlated to the total content of phenolic compounds than to anthocyanin content. No significant correlation was observed between the ability to scavenge DPPH$^{\cdot}$ radicals and ascorbic acid content [115].

Biological Activity and Medicinal Properties of the Bioactive Compounds of Berry Fruits

The diversity of bioactive compounds found in berry fruits and processed fruit products is reflected in the broad spectrum of their biological and medicinal properties.

Chokeberry fruit and its products supplement the treatment of hypertension, atherosclerosis and gastrointestinal tract disorders. The bioactive compounds found in chokeberry strengthen blood vessel walls and improve their elasticity. Chokeberry juice improves peripheral circulation of the blood and boosts the body's resistance to infections [30].

The compounds found in bilberry also have a beneficial impact on the circulatory system. Bilberry anthocyanins improve the elasticity and permeability of the capillary vessels of the eyeball, thus improving microcirculation of the blood and vision at dusk and at night. Owing to those properties, the anthocyanins of bilberry are applied in the production of ophthalmic preparations [117, 118].

Cranberry juice is used in the prevention and treatment of urinary system infections [119, 120, 121], as well as in the treatment of periodontitis [122–124] and other disorders. Yamanaka et al. [123] reported that cranberry juice can inhibit the colonization of the tooth surface by oral streptococci, and thus slow the development of dental plaque. By using a microplate system, these authors found that the high-molecular weight constituents of cranberry juice inhibited biofilm formation by the tested streptococci. Labrecque et al. [124] suggest that cranberry NDM (non-dialyzable material) may contribute to the prevention and treatment of periodontitis by reducing the capacity of *Porphyromonas gingivalis* to colonize periodontal sites. Howell [122] reported that high-molecular weight proanthocyanidins (condensed tannins) from cranberry juice inhibit the adherence of uro-pathogenic fimbriated *Escherichia coli* and thus offer protection against urinary tract infections. Furthermore, a high-molecular weight cranberry fraction was also reported to inhibit the sialic acid-specific adhesion of *Helicobacter pylori* to human gastric mucosa, a critical step for gastric ulcer development [125].

In recognition of their biological activity, phenolic compounds have been long used as natural remedies in the treatment of various diseases (circulatory, respiratory, digestive and urinary system ailments). They are applied in the production of various pharmaceutical products due to their ability to seal capillary vessels and improve circulation. Despite widespread research and the documented wide range of biological activity of those compounds, the mechanism responsible for their beneficial effect on the human body has not been sufficiently investigated [30, 33, 56, 104, 117, 120, 122].

In addition to provitamin activity and antioxidant properties, carotenoids, including β-carotene, have several other functions in the body at the molecular level where they act as immunomodulators, inhibit mutagenesis and prevent malignant transformations [80]. In addition to its antioxidant properties, vitamin C participates in other important biochemical transformations such as the synthesis of collagen, neurotransmitters and hormones. It facilitates the absorption of nonheme iron and stimulates immunological resistance. Vitamin C is a detoxicant—it neutralizes various mutagenic and cancerogenic compounds which are formed in the alimentary system or which enter the digestive tract with food. Thanks to those properties as well as its antioxidant activity, vitamin C is regarded as an effective remedy in inhibiting the development of cancer [126, 127].

Conclusions

The presented characteristics of various berry fruit species point to vast differences in the type of their bioactive compounds. Such differences are observed with regard to both the content and the qualitative composition of those compounds. The most significant health benefits are ascribed to phenolic compounds and vitamin C. Owing to the rich and diversified composition of bioactive compounds and their health-promoting properties which result mostly from their antioxidant activity, berry fruits are widely recognized as natural functional products.

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