Chapter 10

Genotype, Environment and Management Practices on Red/Dark-Colored Fruits Phenolic Composition and Its Impact on Sensory Attributes and Potential Health Benefits

Fernanda Cosme, Berta Gonçalves,
Eunice A. Bacelar, António Inês,
António M. Jordão and Alice Vilela

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Abstract

Phenolic compounds are secondary metabolites abundant in our diet. These compounds may affect positively or negatively the sensory characteristics of food with important impacts on color, flavor, and astringency. An adequate consumption of phenolic compounds may also offer health benefits. After the consumption of fruits, the colon is the main site of microbial fermentation, where high molecular weight phenolic compounds are transformed into low molecular weight phenolic compounds such as phenolic acids or lactone structures by intestinal microbiota, which produce metabolites with biological and antioxidant activity, with evidence on health benefits for humans. A large amount of different phenolic compounds are responsible for physicochemical and sensory characteristics of table grapes and wines. Also, sweet cherry (*Prunus avium* L.) is one of the most popular temperate table fruits; they contain flavonoids, flavan-3-ols, and flavonols in addition to non-flavonoid compounds. Anthocyanins are the major polyphenols in blueberries, and this group of phytochemicals is thought to be responsible for many of the health benefits of berry consumption. Therefore, considering the importance of red/dark-colored fruits phenolic composition, the purpose of this chapter is to make a review of the most recent publications about these fruits' phenolic composition and their impact on sensorial properties as well as the effect of microorganisms on fruit phenolic composition.

Keywords: phenolic compounds, grapes, sweet cherries, blueberries, sensorial characteristics

1. Introduction

Phenolic compounds (phenolic acids, flavonoids, and stilbenes) are today among the most important classes of phytochemicals, since they are responsible for disease protection conferred from diets rich in these compounds [1]. Some fruits with high content of phenolic compounds, including flavonols, flavones, anthocyanins, and phenolic acids are grapes, sweet cherries, and blueberries. Polyphenolic compounds form complexes with salivary proteins, playing a role in the sensation of astringency, due to delubrication of oral surfaces. For astringency, the tannin molecular weight seems to be important for its perception and to the interactions with salivary proteins. Flavor and color are also important factors for the selection of fruit by consumers. Sweetness and bitterness are mutually suppressed in mixtures, but astringency and bitterness tend to be perceived as negative attributes. Polyphenols' sensory properties are related to molecules specific structures, including pigments correlated to fruit color [2]. This richness in phenolic compounds is also directly related with the positive effects on human health. However, the phenolic composition of the red/dark-colored fruits depends on cultivar, maturity, growing environment, cultural practices, postharvest conditions, and processing techniques [3].

2. Phenolic composition of red/dark-colored fruits

2.1. Phenolic composition of wine grapes and table grapes

Grapevine (*Vitis vinifera* L.) is the most important Mediterranean fruit crop, used to produce wine, table grapes, and raisins. The phenolic compounds in grapes include two classes of phenolic compounds: non-flavonoids and flavonoids. The major C_6-C_3-C_6 flavonoids in grapes include conjugates of flavonols, quercetin, and myricetin; flavan-3-ols (+)-catechin and (-)-epicatechin; and malvidin-3-*O*-glucoside and other anthocyanins. Non-flavonoids include C_6-C_1 hydroxybenzoic acids, and gallic acid, C_6-C_3 hydroxycinnamates caffeic, caftaric, and *p*-coumaric acids; and C_6-C_3-C_6 stilbenes *trans*-resveratrol, *cis*-resveratrol, and *trans*-resveratrol glucoside. Polyphenols are a diverse group of secondary metabolites, which exist in different grape bunch fraction, such as stems, skins, pulp, and seeds [4–8]. According to Pastrana-Bonilla et al. [6], the average concentration of total phenolic compounds in wine grapes is around 2178.8 mg/g gallic acid equivalent, in seeds, 374.6 mg/g gallic acid equivalent, in skins, and 23.8 mg/g gallic acid equivalent, in pulps. In addition, for table grapes, several authors also reported high levels of global and individual phenolic compounds [9]. Also for grape raisins, several works reported high levels of phenolic compounds [10, 11]. Thus, Sério et al. [12] reported levels of total phenolic compounds from several commercial red raisins (namely from Cardinal and Moscatel of Alexandria grape varieties) that ranged from 110.8 to 406.9 mg/100 g raisin. Phenolic compounds play an important role in wine quality and also in sensorial characteristics of table grapes, such as color, astringency, bitterness, and aroma. However, it is important to note that the phenolic composition of grape berries depends on grape variety, environmental factors, and viticultural practices [8, 13–15]. Consequently, all these isolated or combined factors will be critical for the composition of

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grape phenolic compounds, grape variety being one of the most important [16, 17]. Thus, genotypic differences among different varieties have a great influence in grape phenolic synthesis and accumulation during grape fruit maturation and development [18]. However, the interaction between the genotype, environment, and management practices heavily influences the overall phenolic composition. Recently, Costa et al. [8] analyzed the phenolic composition of several grape varieties cultivated at the same time in two Portuguese regions with distinct climatic conditions and reported that in general significantly higher global phenolic composition was obtained in the grapes collected in one of the regions. In addition, other work recently published [15] analyzed the adaptability of several red grape varieties from French origin to the other specific "terroirs" and compare their characteristics with native grape varieties. These authors reported that French grape varieties studied showed a higher degree of adaptation of the climate and soil conditions from the Portuguese vineyards, especially for phenolic composition. Thus, grape phenolic characteristics are strongly influenced by environmental conditions specific from each place and consequently each grape variety produced in a specific terroir reflects the locality in its chemical composition, including in phenolic composition. According to several works, the geological and soil conditions [19], vineyard altitude [20], sunlight exposition [21], climate [21, 22], and solar radiation [23] of a region are important environmental factors that determine grape phenolic composition. Finally, there are also other factors that directly or indirectly may determine the grape phenolic composition, namely cultivation practices [22], exposure to diseases [24], and the degree of grape ripeness [4, 17].

2.2. Phenolic composition of sweet cherry

Cherries are an excellent source of antioxidants, particularly phenolics, such as flavonoids, flavan-3-ols, and flavonols in addition to non-flavonoid compounds such as hydroxycinnamic and hydroxybenzoic acids, which are concentrated in the epicarp and mesocarp of the fruit [25, 26]. The most abundant phenolic compounds are anthocyanins such as cyanidin-3-*O*-rutinoside, cyanidin-3-*O*-glucoside, peonidin-3-*O*-rutinoside and glucoside, as well as pelargonidin-3-*O*-rutinoside are the most important anthocyanins in cherries [27]. The total anthocyanin content ranged from 6.21 to 94.20 mg cyanidin-3-*O*-glucoside equivalents/100 g fresh weight in 24 sweet cherry cultivars grown on the mountain sides of the Etna volcano (Sicily, Italy) [28]. Other phenolics in cherries include neochlorogenic acid, *p*-coumaroylquinic acid, and chlorogenic acid as the main hydroxycinnamic acids [26, 29, 30], the flavonol rutin and the flavan-3-ols (+)-catechin and (-)-epicatechin (**Figure 1**) [26, 31]. The total phenol content ranged from 84.96 to 162.21 mg gallic acid equivalents/100 g fresh weight in 24 sweet cherry cultivars grown in Italy [28]. Moreover, several studies reported higher phenolic content [26, 32] and antioxidant activity [32] in ripe cherries than in partially ripe. However, other pre- and postharvest factors, such as rootstock, cultivar, climate, soil type, storage conditions, and processing can significantly alter the amounts of bioactive compounds. In fact, levels of chlorogenic acid, neochlorogenic acid, *p*-coumaric acid, and quercetin-3-rutinoside were higher in fruits grown on Weiroot 13 and PiKu 1 rootstocks compared to MaxMa 14, Weiroot 158, F12/1 and Gisela 5 rootstocks [31]. According to Gonçalves et al. [26], the cherry cultivars have the same phenolic pattern, however, with large variation on content as presented in **Table 1**. The climatic conditions have great

influence on phenolic levels. Indeed, Gonçalves et al. [26] stated that higher temperature and solar irradiation favored the biosynthesis of phenolic acids and decreased the content of anthocyanins. However, the phenolic content tends to reach highest levels in the late stage of final maturity as refereed by Stöhr et al. [33]. In recent research, the preharvest application of several products to improve cherry quality, such as the oxalic acid (2 mM), has been studied, which increased anthocyanins, flavonols, neochlorogenic, and chlorogenic acids [34]. All the phenolic compounds and the antioxidant activity increased in several sweet cherry cultivars during cold storage [26, 27, 32, 35]. Also, the level of phenolics in "Canada Giant" and "Ferrovia" cherries increased during 8 days of shelf life [36]. Nevertheless, Esti et al. [37] detected a total anthocyanin content decrease of 41–52% in two sweet cherry cultivars after 15 days at 1°C and 95% RH. The use of edible coatings has been used to extend the postharvest storage of cherries. Petriccione et al. [38] specified that chitosan-coated sweet cherries presented higher total phenolic, flavonoid, and anthocyanin levels. Moreover, increasing health-promoting properties of cherry fruit can be achieved with the addition of methyl salicylate treatment to cherry trees. This compound also delays the fruit postharvest senescence process by increasing the activity of the enzymes involved in ROS scavenging [39].

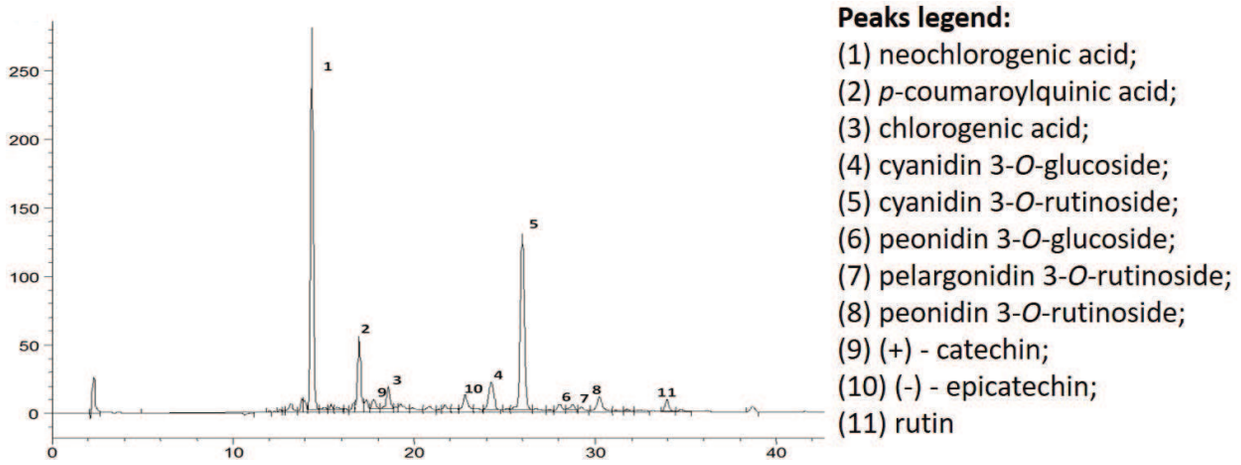

Figure 1. HPLC chromatogram of the Van sweet cherry cultivar extracts recorded at 280 nm. Adapted from Gonçalves et al. [26].

Cultivar	Hydroxycinnamic acids			Flavan-3-ols		Flavonols	Anthocyannis				
	NcAc	*p*CqAC	CAc	Cat	Epi	Rut	cy-3-glu	cy-3-rut	pn-3-glu	plg-3-rut	pn-3-rut
Burlat	23.8	24.7	3.8	7.2	6.7	4.8	23.2	44.6	<1.0	<1.0	2.1
Saco	153.5	12.2	9.8	10.5	10.3	11.8	5.1	38.6	n.d.	<1.0	<1.0
Summit	34.4	27.5	7.2	5.8	8.2	3.1	2.4	26.0	<1.0	<1.0	<1.0
Van	65.6	5.6	4.8	3.5	4.5	4.0	3.4	28.2	<1.0	<1.0	1.5

NcAc, neochlorogenic acid; *p*CqAC, *p*-coumaroylquinic acid; CAc, chlorogenic acid; Cat, catechin; Epi, epicatechin; Rut, Rutin; cy-3-glu, cyanidin-3-*O*-glucoside; cy-3-rut, cyanidin-3-*O*-rutinoside; pn-3-glu, peonidin-3-*O*-glucoside; plg-3-rut, pelargonidin-3-*O*-rutinoside; pn-3-rut, peonidin-3-*O*-rutinoside; n.d., not detected.
Adapted from Gonçalves et al. [26].

Table 1. Content of several phenolic compounds in four sweet cherry cultivars (mg /100g fresh weight).

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Almost all phenolic compounds in sweet cherry show strong antioxidant activity [35, 40, 41]. Adequate consumption of phenolic compounds may offer health benefits that include inhibition of tumor cells growth [41], inhibition of inflammation [42], and protection against neurodegenerative diseases [43]. According to Matias et al. [44], a phenolic-rich extract derived from sweet cherries could be an attractive candidate to formulate an agent for the prevention of oxidative stress-induced disorders such as intestinal inflammation disorders. In spite of the large variations in the phenolic compounds content observed among several cherry cultivars, the levels of health-promoting compounds are relevant to human health. Sweet cherries might therefore be considered as a functional food [41]. In fact, cyanidin-3-*O*-rutinoside can slow down the absorption of carbohydrates by the inhibition of α-glucosidase which may therefore be useful as inhibitor to prevent or treat diabetes mellitus [45]. Cyanidin-3-*O*-glucoside showed cardioprotective effects by reducing blood lipid levels in rats [46]. The oxygen radical absorbance capacity (ORAC) assay indicated that the fruit of all genotypes possessed considerable antioxidant activity [28]. Moreover, several cherry cultivars were effective in inhibiting human cancer cells derived from colon (HT29) and stomach (MKN45) [41]. Finally, cherry phenolic, mainly anthocyanins, also protects neuronal PC 12 cells from cell-damaging oxidative stress (antineurodegenerative activity). However, this protection is dose-dependent [43].

2.3. Phenolic composition of blueberries

Blueberries are flowering plants of the genus *Vaccinium* with dark-purple berries, whose anthocyanins are considered to be nature's most potent antioxidants [47]. The genus *Vaccinium* belongs to the *Ericaceae* family [48] and includes many popular berries consumed around the world including blueberries, huckleberries, cranberries, lingonberries, and bilberries [49]. Of the more than 400 species in the genus *Vaccinium*, highbush, lowbush, and rabbiteye blueberries (*V. corymposum* L., *V. augustifolium* Ait., and *V. ashei* Reade, respectively) are of high economic importance [50]. In fact, in recent years the production of these fruits has increased rapidly in Europe and across the globe, as a result of the recognition of their high nutritive value, characteristic taste, and flavor but also due to recent press regarding the health benefits of fresh berries consumption [51, 52]. Over 89,820 acres of land are growing cultivated blueberries with an estimated annual production of 280,000 tons [53]. Blueberries are both a food product and a dietary supplement, consumed not only as fresh fruits but also as frozen fruits, or in dried or preserved form in bakery products. Blueberry anthocyanins are used as a natural food colorant [54] and blueberry extract can be used as a prebiotic [49]. The fruit quality traits and the phytochemical content of blueberries are of increasing importance to researchers in the field of food and health [55]. Blueberries are a source of vitamins, minerals, dietary fiber, phenolics, and flavonoids and they are very low in fat and sodium [56]. Anthocyanins, which provide blueberry with their characteristic colors, are the major polyphenols in blueberries and this group of phytochemicals is thought to be responsible for many of the health benefits of berry consumption [57]. The anthocyanins detected in blueberries are 3-glycosidic derivatives of cyanidin, delphinidin, malvidin, petunidin, and peonidin [49]. Nevertheless, anthocyanins vary in their quantity and composition among genotypes and also depend on the environmental growth conditions, postharvest storage conditions, and the method of analysis. Anyway, malvidin-3-glucoside and malvidin-3-galactoside have been found to be

the two most predominant anthocyanins in many cases [58]. Blueberries also contain varying amounts of other polyphenols, and chlorogenic acid is particularly high as compared with other food sources [59]. It is accompanied by small amounts of quercetin glycosides [60].

3. Impact of fruit phenolic compounds on sensorial characteristics

Regarding fruit's oral sensory characteristics, there are six oral sensory attributes of fruit: sourness, sweetness, bitterness, spiciness, aroma, and astringency. For many people, the oral sensory properties of fruit have a great impact on their choice, acceptability, and consumption. Phenolic compounds, apart from possessing valuable biological properties, impart a high sensory activity to foods [61]. They are closely associated with the sensory and nutritional quality of fresh and processed plant foods and may affect positively or negatively the sensory characteristics of food with impacts on color, flavor, and astringency. This impact becomes important for consumer's acceptance, so that health-promoting products can be palatable and largely consumed [2]. Fruit preservation also influences the quantity and quality of fruits' phenolic content. For instances, during thawing of fruits, oxidation of phenolic compounds takes place and is negatively correlated with the acceptance level of fruits [62]. However, in a study comparing different pretreating processes of strawberries, samples with the highest phenolic content were also the most pleasant ones [63]. Specific structures are described to be related to polyphenols' sensory properties, namely color perception. Color, in fruits, is derived from natural pigments that change through plant ripening. Chlorophylls (green), carotenoids (yellow, orange, and red), anthocyanins (red and blue), flavonoids (yellow), and betalains (red) are the primary pigments responsible for fruit color [64]. Also, water-soluble brown-, gray-, and black-colored pigments may occur due to enzymatic and non-enzymatic browning reactions [65]. Many polyphenol pigments in plants are reactive anthocyanins, yellow flavanols, and flavones [66]. Anthocyanins can be used in food industry to color food. The six anthocyanins that can be found in the following red/dark-colored fruits are cyanidin (cherries, blackcurrants, raspberries, and elderberries), delphinidin (blackcurrants and blueberries), malvidin (grapes), pelargonidin (strawberries and radishes), peonidin (cranberries), and petunidin (blueberries)—**Figure 2**. Due to their water solubility, anthocyanins are applicable for dyeing low pH systems. Increasing pH leads to a lesser color intensity and a bluer tone appears at pH higher than 4.5, giving its bluish color to blackcurrant. Proanthocyanidins react with anthocyanins to form new red pigments [68]. Loss or stabilization of color and increases in the range of available hues are resulted by the conversion of anthocyanins to other compounds during food processing [2]. The color of fruits is a sensory attribute that can really change consumers' fruit acceptance. It is considered the most important product-intrinsic sensory cue leading the sensory expectations that the consumer holds concerning the foods that they may consume [69] and, according to Piqueras-Fizman et al. [70], humans' experience of taste/flavor is determined by the expectations that they often generate prior to tasting. Consumers inspect fruits, visually, before deciding on whether or not to buy them. People associate certain colors with certain flavors. For instances, red/dark fruit coloring also appears to be a particularly good inducer of sweetness [71].

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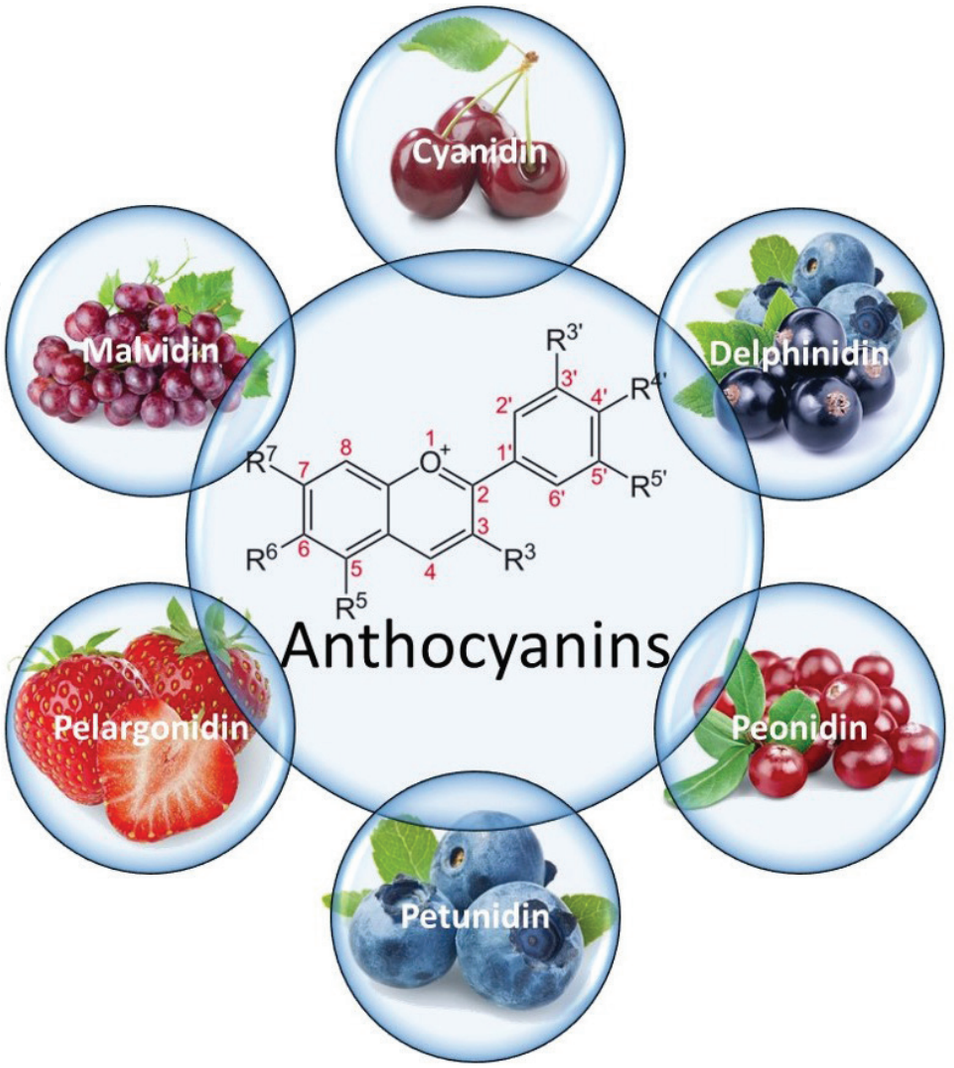

Figure 2. Anthocyanins in red/dark-colored fruits. Adapted from Just the Berries [67].

Gavrilova et al. [72] studied the phenolic profile of four blueberry varieties (*V. corymbosum* L., cv. Toro, Legacy, Duke, and Bluecrop) and two varieties (Rosenthal and Rovada) of red currants (*Ribes rubrum* L.) and black currants (*R. nigrum* L.) cultivated in Macedonia. They found that anthocyanins comprised the highest content of total phenolic compounds in currants (>85%), namely in the dark (black) currents, and lower and variety dependent in blueberries (35–74%). Hydroxycinnamic acid derivatives comprised 23–56% of total phenolics in blueberries and 1–6% in currants (**Table 2**). Besides bitterness, astringency, and color, some volatile polyphenols are strong odorants [66]. However, in dark-colored fruits, phenolic compounds present an almost insignificant role in fruit flavor profile. In raspberry fruit (*Rubus idaeus* L.), phenolic compounds only represent 1% of the total flavor compounds (**Figure 3**), whose concentration varies between "trace amount" and 0.3 mg/kg [73]. Nevertheless, in wild berries, several volatile phenolic compounds were identified by Honkanen et al. [73], such as 2-methoxy-4-vinylphenol, 2-methoxy-5-vinylphenol, 3,4-dimethoxybenzaldehyde, and 4-vinylsyringol, none of which have been reported in cultivated varieties [74]. An important fact

stated by Honkanen et al. [73] is that with the exception of ionones, the amounts of individual volatile compounds in wild raspberries were generally three to four times higher than in the cultivated varieties. Moreover, the higher amounts of volatile compounds, in wild raspberry, may have contributed to their characteristic aroma. Also, the increased berry size, hybridization, and/or fertilization lead to worsening in the aroma profile of cultivated raspberries.

	Red currants		**Black currants**		**Blueberries**			
Compounds (total)	**Rosenthal**	**Rovada**	**Rosenthal**	**Rovada**	**Toro**	**Legacy**	**Duke**	**Bluecrop**
Phenolic compounds.	18.05 ± 0.58	17.97 ± 0.31	207.77 ± 1.14	187.69 ± 1.84	94.60 ± 0.93	137.74 ± 1.05	113.02 ± 1.28	120.14 ± 1.02
Anthocyanins	15.93 ± 0.95	14.73 ± 0.29	180.44 ± 3.59	162.83 ± 2.46	56.35 ± 1.04	68.55 ± 2.35	83.64 ± 3.16	41.99 ± 0.25
Flavonols	1.89 ± 0.08	0.48 ± 0.005	7.36 ± 0.57	6.95 ± 0.92	2.28 ± 0.80	5.17 ± 0.03	3.41 ± 0.16	6.08 ± 0.45
Flavan-3-ols	n.d.	1.60 ± 0.002	13.35 ± 0.90	11.02 ± 1.23	2.85 ± 0.54	1.75 ± 0.07	n.d.	4.52 ± 0.43
Hydroxycinnamic acid derivatives	0.23 ± 0.002	1.16 ± 0.10	6.62 ± 0.18	6.89 ± 0.24	33.12 ± 1.78	62.27 ± 1.97	25.97 ± 3.21	67.54 ± 3.03

n.d., not detected.

Table 2. Contents of phenolic compounds in red currants (*Ribes rubrum* L.), black currants (*Ribes nigrum* L.), and blueberries (*Vaccinium corymbosum* L.) determined by HPLC-DAD and expressed in mg per 100 g fresh weight±SD (n = 3). Adapted from Gavrilova et al. [72].

Plant-based phenol compounds, flavonoids, isoflavones, terpenes, and glucosinolates are almost bitter and astringent [75]. These substances provide defense against predators by making the plants unpalatable [75]. But also humans reject foods that are perceived to be excessively bitter [76]. Flavonoid phenols have been indicated as the main responsible for the taste of bitterness and the mouth-fell sensation of astringency in several types of fruits and in beverages [2, 77]. Several works suggested that some polyphenols can be responsible for the bitterness of fruits even if they are present in very low concentrations [78]. The bitterness and astringency of red wines and red/dark-colored fruits are mainly given by the flavanols. The mechanisms through which bitter taste perception occurs are not well understood; however, it is known that these mechanisms involve the activation of distinct human bitter taste receptors [77, 78]. While lower-molecular-weight phenolic compounds tend to be likely bitter, higher-molecular-weight polymers are perceived as astringent. Astringency or drying/puckering mouth-feel detectable throughout the oral cavity is due to a complex reaction between polyphenols and proteins of the mouth and saliva [79]. Interaction between tannins and saliva proteins plays an important role in astringency perception in wine [80]; however, the physiological and physicochemical mechanisms for this phenomenon are not fully understood and more studies focusing on this subject must be done in wines and fruits.

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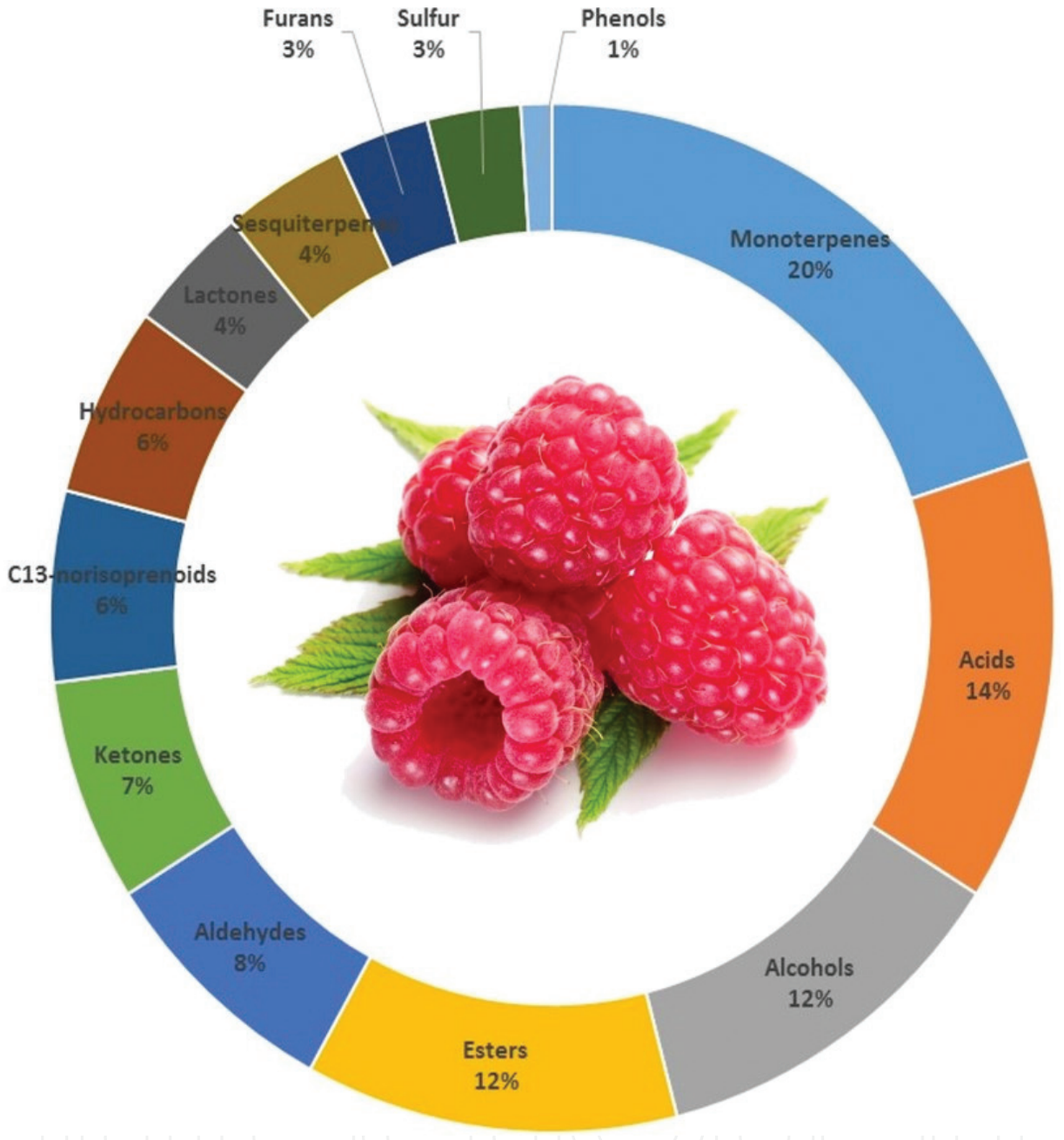

Figure 3. Volatile compounds reported in raspberry fruit (*Rubus idaeus* L.) according to chemical class. Adapted from Aprea et al. [74].

Total concentration, mean degree of polymerization [81], subunit composition, and distribution [82] are some of the variables related to tannins, highly correlated with the perception of astringency in fruits. Tannins vary in size, from dimers up to oligomers, with more than 30 subunits [83]. Polymer size affects astringency correlating positively with the perception of astringency [84]. Increased galloylation can be responsible for increased "abrasiveness" while trihydroxylation of the B-ring can decrease it [85]. As referred by He et al. [86], the synthesis of astringent substances controlled by a variety of structural and regulatory genes must be studied. Moreover, these authors state that "(…) cloning and functional identification of genes, in

the astringency metabolic pathway, and their spatio-temporal expression patterns as well as tannin biosynthesis-related transcription factor genes must be considered in future work to finally make it possible to control fruit astringent substances quantitatively (…)"[86].

4. Effect of microorganisms on fruit phenolic compounds

After the consumption of fruits, the colon is the main site of microbial fermentation, where high molecular weight phenolic compounds are transformed into low molecular weight phenolic compounds such as phenolic acids or lactone structures by intestinal microbiota. The human healthy adult gut microbiota already identified can be classified into three dominant phyla: *Bacteroidetes*, *Firmicutes* and *Actinobacteria*. This highly complex and diverse bacterial ecosystem is mainly composed by a dominant group(> 109 Colony Forming Units (CFU)/g) of anaerobic bacteria, including genera *Bacteroides*, *Eubacterium*, *Bifidobacterium*, *Peptostreptococcus*,

Precursors			Major metabolites	Bacteria	Ref.
Flavonoids	Flavan-3-ols	Myricetin	2-(3,5-Dihydroxyphenyl) acetic acid 2-(3-Hydroxyphenyl) acetic acid	*Clostridium orbiscidens, Eubacterium oxidoreducens*	[90–92]
		Quercetin	3-(3,4-Dihydroxyphenyl) propionic acid 3-(3-Hydroxyphenyl)propionic acid		[91–93]
		Kaempferol	2-(4-Hydroxyphenyl)propionic acid 2-(3,4-Dihydroxyphenyl)acetic acid 2-(3-Hydroxyphenyl)acetic acid		[90]
		Catechin	3-(3-Hydroxyphenyl)propionic acid 5-(3',4'-Dihydroxyphenyl)-γ-valerolactone	*Clostridium coccoides, Bifidobacterium* spp.	[94–97]
		Epicatechin	5-(3,4-Dihydroxyphenyl) valeric acid 3-(3,4-Dihydroxyphenyl)propionic acid		
		Epigallocatechin	5-(3',4'-Dihydroxypheny[l)-γ-valerolactone 5-(3',5'-Dihydroxyphenyl)-γ-valerolactone		
	Anthocyanins	Malvidin	3,4-Dimethoxybenzoic acid	*Lactobacillus (plantarum, casei, acidophilus LA-5) Bifidobacterium lactis BB-12*	[98, 99]
		Cyanidin	3,4-Dihydroxybenzoic acid		
		Peonidin	3-Methoxy4-hydroxybenzoic acid		
		Pelargonidin	4-Hydroxybenzoic acid		
Non-flavonoids	Hydroxycinnamates	Caffeic, ferulic, and *p*-coumaric acids linked to a quinic acid to form, respectively, caffoylquinic feruloylquinic, and *p*-coumaroylquinic acids	3-Hydroxyphenyl propionic acid Benzoic acid 3-(4-Hydroxyphenyl) propionic acid Vanillin	*Escherichia coli, Bifidobacterium lactis, Lactobacillus gasseri*	[100–102]

Table 3. Major metabolites resulting by phenolic compounds (flavonoids and non-flavonoids) biodegradation and bacteria implicated in their transformation (adapted from Marín et al. [88]).

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Ruminococcus, Clostridium and Propionibacterium, and sub-dominant groups (< 109CFU/g), of bacteria of the Enterobacteriaceae family, especially E. *coli*, and the genera *Streptococcus, Enterococcus, Lactobacillus, Fusobacterium, Desulfovibrio* and *Methanobrevibacter* [89]. Thus, the microbial metabolism (**Table 3**) of most of the phenolic classes such as flavonoids, isoflavonoids, lignans, phenolic acids, and tannins may produce metabolites with biological activity, presenting increased antioxidant activity, with evidence on health benefits for consumers. As most dietary polyphenolic compounds occur in glycosylated form in plants [87], for acquiring bioactivity in human body after being absorbed at enterocytes, these compounds must suffer various intestinal transformations, including the activities of digestive and microbial enzymes [88]. After cleavage of sugar responsible for glycosylation, the final absorbed compounds enter the vein circulation toward liver (**Figure 4**). Other enzymatic transformations occur from the liver to other organs, including digestive tract or via blood being excreted by urine [88].

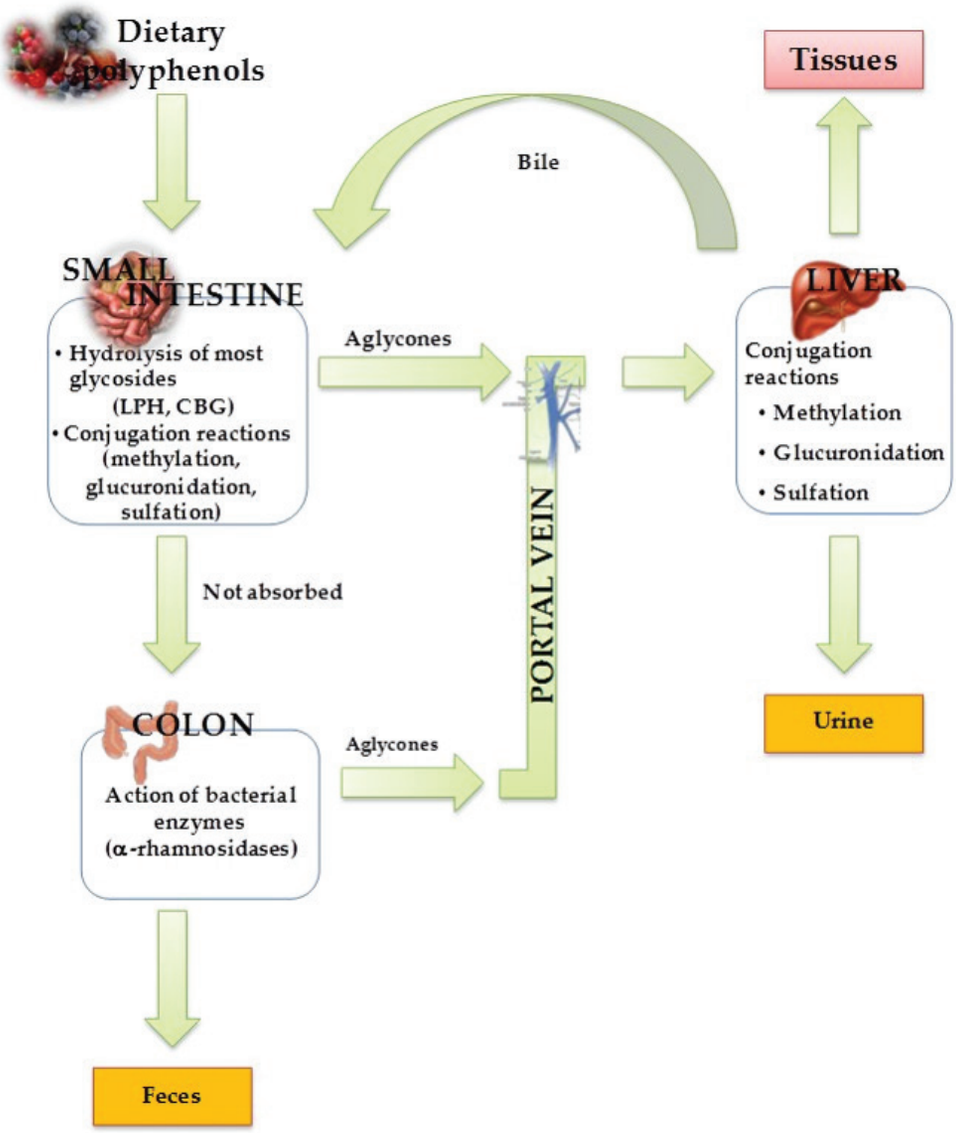

Figure 4. Absorption and metabolism routes for dietary polyphenols and their derivatives in humans. Adapted from Marín et al. [88].

5. Final remark

Red/dark-colored fruits are considered healthy and nutritious, the major potential health benefits being a reduced risk for cardiovascular and neurodegenerative diseases. Phytochemicals from red/dark-colored fruits are also shown to prevent body weight gain, lower blood cholesterol, and reduce cancer risk. Nevertheless, further rigorous, prospective studies are needed in order to better understand the benefits included in red/dark-colored fruits in our diet. There is also an emergent interest in the study of red/dark-colored fruits astringency because of the healthy properties of astringent substances found in red/dark-colored fruits including antibacterial, antiviral, anti-inflammatory, antioxidant, anticarcinogenic, antiallergenic, hepatoprotective, and vasodilating. The role of phenolic compounds and their metabolites as prebiotics, contributing to beneficial gastrointestinal health effects by modulating gut microbial balance with the simultaneous inhibition of pathogens and stimulation of beneficial bacteria, should also be highlighted.

Author details

Fernanda Cosme[1]*, Berta Gonçalves[2], Eunice A. Bacelar[2], António Inês[1], António M. Jordão[3] and Alice Vilela[1]

*Address all correspondence to: fcosme@utad.pt

1 Department of Biology and Environment, School of Life Sciences and Environment, CQ-VR, Chemistry Research Centre, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal

2 Department of Biology and Environment, School of Life Sciences and Environment, CITAB, Centre for the Research and Technology of Agro-Environmental and Biological Sciences, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal

3 Polytechnic Institute of Viseu (CI&DETS), Agrarian Higher School, Estrada de Nelas, Quinta da Alagoa, Ranhados, Viseu, Portugal

References

[1] Arts IC, Hollman PC: Polyphenols and disease risk in epidemiologic studies. American Journal of Clinical Nutrition, 2005, **81** (1 Suppl.): 317S–325S.

[2] Oliveira LL, Carvalho MV, Melo L: Health promoting and sensory properties of phenolic compounds in food. Revista Ceres, 2014, **61** (Suppl.): 764–779. DOI: 10.1590/0034-737x201461000002

[3] Kårlund A, Moor U, Sandell M, Karjalainen RO: The impact of harvesting, storage and processing factors on health-promoting phytochemicals in berries and fruits. Processes, 2014, **2**: 596–624. DOI: 10.3390/pr2030596

[4] Jordão AM, Ricardo-da-Silva JM, Laureano O: Evolution of proanthocyanidins in bunch stems during berry development (*Vitis vinifera* L.). Vitis, 2001, **40**: 17–22.

[5] Jordão AM, Ricardo-da-Silva JM, Laureano O: Evolution of catechins and oligomeric procyanidins during grape maturation of Castelão Francês and Touriga Francesa. American Journal of Enology and Viticulture, 2001, **53**: 231–234.

[6] Pastrana-Bonilla E, Akoh CC, Sellappan S, Krewer G: Phenolic content and antioxidant capacity of muscadine grapes. Journal of Agricultural and Food Chemistry, 2003, **51**: 5497–5503. DOI: 10.1021/jf030113c

[7] Cosme F, Ricardo-Da-Silva JM, Laureano O: Tannin profiles of *Vitis vinifera* L. cv. red grapes growing in Lisbon and from their monovarietal wines. Food Chemistry, 2009, **112**: 197–204. DOI: 10.1016/j.foodchem.2008.05.058

[8] Costa E, Cosme F, Rivero-Pérez MD, Jordão AM, González-SanJosé ML: Influence of wine region provenance on phenolic composition, antioxidant capacity and radical scavenger activity of traditional Portuguese red grape varieties. European Food Research and Technology, 2015, **241**: 61–73. DOI: 10.1007/s00217-015-2434-x

[9] Eyduran SP, Akin M, Ercisli S, Eyduran E, Maghradze D: Sugars, organic acids, and phenolic compounds of ancient grape cultivars (*Vitis vinifera* L.) from Igdir province of Eastern Turkey. Biological Research, 2015, **48**: 1–8. DOI: 10.1186/0717-6287-48-2

[10] Meng J, Fang Y, Zhang A, Chen S, Xu T, Ren Z, Han G, Liu J, Li H, Zhang Z, Wang H: Phenolic content and antioxidant capacity of Chinese raisins produced in Xinjiang Province. Food Research International, 2011, **44**: 2830–2836. DOI: 10.1016/j.foodres.2011.06.032

[11] Ghrairi F, Lahouar L, Amira A, Brahmi F, Ferchichi A, Achour L, Said S: Physicochemical composition of different varieties of raisins (*Vitis vinifera* L.) from Tunisia. Industrial Crops and Products, 2013, **43**: 73–77. DOI: 10.1016/j.indcrop.2012.07.008

[12] Sério S, Rivero-Pérez MD, Correia AC, Jordão AM, González-San José ML: Analysis of commercial grape raisins: phenolic content, antioxidant capacity and radical scavenger activity. Ciência e Técnica Vitivinícola, 2014, **29**: 1–8. DOI: 10.1051/ctv/20142901001

[13] Jordão AM, Ricardo-da-Silva JM, Laureano O: Influence of irrigation on the phenolic composition of red grapes from the Touriga Francesa variety (*Vitis vinifera* L.). CyTA - Journal of Food, 1998, 2: 60–73. DOI: 10.1080/11358129809487584.

[14] Pérez-Magariño S, González-Sanjosé ML: Polyphenols and colour variability of red wines made from grapes harvested at different ripeness grade. Food Chemistry, 2006, **96**: 197–208. DOI: 10.1016/j.foodchem.2005.02.021

[15] Costa E, Da Silva JF, Cosme F, Jordão AM: Adaptability of some French red grape varieties cultivated at two different Portuguese terroirs: comparative analysis with two Portuguese red grape varieties using physicochemical and phenolic parameters. Food Research International, 2015, **78**: 302–312. DOI: 10.1016/j.foodres.2015.09.029

[16] Monagas M, Gómez-Cordovés C, Bartolomé B, Laureano O, Ricardo-da-Silva JM: Monomeric, oligomeric, and polymeric flavan-3-ol composition of wines and grapes from *Vitis vinifera* L. Cv. Graciano, Tempranillo, and Cabernet Sauvignon. Journal of Agricultural and Food Chemistry, 2003, **51**: 6475–6481. DOI: 10.1021/jf030325+

[17] Obreque-Slier E, López-Solís R, Castro-Ulloa L, Romero-Díaz C, Peña-Neira A: Phenolic composition and physicochemical parameters of Carménère, Cabernet Sauvignon, Merlot and Cabernet Franc grape seeds (*Vitis vinifera* L.) during ripening. LWT - Food Science and Technology, 2012, **48**: 134–141. DOI: 10.1016/j.lwt.2012.02.007

[18] He JJ, Liu YX, Pan QH, Cui XY, Duan CQ: Different anthocyanin profiles of the skin and the pulp of Yan73 (Muscat Hamburg× Alicante Bouschet) grape berries. Molecules, 2010, **15**: 1141–1153. DOI: 10.3390/molecules15031141

[19] Ubalde JM, Sort X, Zayas AA, Poch RM: Effects of soil and climatic conditions on grape ripening and wine quality of Cabernet Sauvignon. Journal of Wine Research, 2010, **21**: 1–17. DOI: 10.1080/09571264.2010.495851

[20] Mateus N, Machado JM, De Freitas V: Development changes of anthocyanins in *Vitis vinifera* grapes grown in the Douro Valley and concentration in respective wines. Journal of the Science of Food and Agriculture, 2002, **82**: 1689–1695. DOI: 10.1002/jsfa.1237

[21] Bergqvist J, Dokoozlian N, Ebisuda N: Sunlight exposure and temperature effects on berry growth and composition of Cabernet Sauvignon and Grenache in the Central San Joaquin Valley of California. American Journal of Enology and Viticulture, 2001, **52**: 1–7.

[22] Downey MO, Dokoozlian NK, Krstic MP: Cultural practice and environmental impacts on the flavonoid composition of grapes and wine: a review of recent research. American Journal of Enology and Viticulture, 2006, **57**: 257–268.

[23] Madeira FC: Effect of ultraviolet radiation b on vine-growing behavior of the variety Cabernet Sauvignon (*Vitis Vinífera* L.) grown on São Joaquim, Santa Catarina. Master dissertation (Master in Plant Genetic Resources), University Federal of Santa Catarina, Florianópolis, Brazil, 2011.

[24] Bruno G, Sparapano L: Effects of three esca-associated fungi on *Vitis vinifera* L: V. Changes in the chemical and biological profile of xylem sap from diseased cv. Sangiovese vines. Physiological and Molecular Plant Pathology, 2007, **71**: 210–229. DOI: 10.1016/j.pmpp.2008.02.005

[25] Gao L, Mazza G: Characterization, quantification and distribution of anthocyanins and colorless phenolics in sweet cherry. Journal of Agricultural and Food Chemistry, 1995, **43**: 343–346. DOI: 10.1021/jf00050a015

[26] Gonçalves B, Landbo AK, Knudsen D, Silva AP, Moutinho-Pereira J, Rosa E: Effect of ripeness and postharvest storage on the phenolic profiles of cherries (*Prunus avium* L.). Journal of Agricultural and Food Chemistry, 2004, **52**: 523–530. DOI: 10.1021/jf030595s

[27] Gonçalves B, Silva AP, Moutinho-Pereira J, Bacelar E, Rosa E, Meyer AS: Effect of ripeness and postharvest storage on the evolution of colour and anthocyanins in cherries (*Prunus avium* L.). Food Chemistry, 2007, **103**: 976–984. DOI: 10.1016/j.foodchem.2006.08.039

[28] Ballistreri G, Continella A, Gentile A, Amenta M, Fabroni S, Rapisarda P: Fruit quality and bioactive compounds relevant to human health of sweet cherry (*Prunus avium* L.) cultivars grown in Italy. Food Chemistry, 2013, **140**: 630–638. DOI: 10.1016/j.foodchem.2012.11.024

[29] Usenik V, Fajt N, Mikulic-Petkovsek M, Slatnar A, Stampar F, Veberic R: Sweet cherry pomological and biochemical characteristics influenced by rootstock. Journal of Agricultural and Food Chemistry, 2010, **58**: 4928–4933. DOI: 10.1021/jf903755b

[30] Liu Y, Liu X, Zhong F, Tian R, Zhang K, Zhang X, Li T: Comparative study of phenolic compounds and antioxidant activity in different species of cherries. Journal of Food Science, 2011, **76**: 633–638. DOI: 10.1111/j.1750-3841.2011.02150.x

[31] Jakobek L, Marijan S, Vóca S, Šindrak Z, Dobričević N: Flavonol and phenolic acid composition of sweet cherries (cv. Lapins) produced on six different vegetative rootstocks. Scientia Horticulturae, 2009, **123**: 23–28. DOI: 10.1016/j.scienta.2009.07.012

[32] Serrano M, Díaz-Mula HM, Zapata PJ, Castillo S, Guillén F, Martínez-Romero D: Maturity stage at harvest determines the fruit quality and antioxidant potential after storage of sweet cherry cultivars. Journal of Agricultural and Food Chemistry, 2009, **57**: 3240–3246. DOI: 10.1021/jf803949k

[33] Stöhr H, Mosel H, Herrmann KZ: VII. The phenolics of cherries and plums and the changes in catechins and hydroxycinnamic acid derivatives during the development of fruits. Lebensmittel-Untersuchung und Forschung, 1975, **159**: 85–91.

[34] Martínez-Esplá A, Zapata PJ, Valero D, García-Viguera C, Castillo S, Serrano M: Preharvest application of oxalic acid increased fruit size, bioactive compounds, and antioxidant capacity in sweet cherry cultivars (*Prunus avium* L.). Journal of Agricultural and Food Chemistry, 2014, **62**: 3432–3437. DOI: 10.1021/jf500224g

[35] Gonçalves B, Landbo AK, Let M, Silva AP, Rosa E, Meyer AS: Storage affects the phenolic profiles and antioxidant activities of cherries (*Prunus avium* L.) on human low-density lipoproteins. Journal of the Science of Food and Agriculture, 2004, **84**: 1013–1020. DOI: 10.1002/jsfa.1752

[36] Goulas V, Minas IS, Kourdoulas PM, Lazaridou A, Molassiotis AN, Gerothanassis IP, Manganaris GA: 1H NMR metabolic fingerprinting to probe temporal postharvest changes on qualitative attributes and phytochemical profile of sweet cherry fruit. Front. Plant Science, 2015, **6**: 1–11. DOI: 10.3389/fpls.2015.00959

[37] Esti M, Cinquanta L, Sinesio F, Moneta E, Di Matteo M: Physiochemical and sensory fruit characteristics of two sweet cherry cultivars after cool storage. Food Chemistry, 2002, **76**: 399–405. DOI: 10.1016/S0308-8146(01)00231-X

[38] Petriccione M, De Sanctis F, Pasquariello MS, Mastrobuoni F, Rega P, Scortichini M, Mencarelli F: The effect of chitosan coating on the quality and nutraceutical traits of sweet cherry during postharvest life. Food and Bioprocess Technology, 2014, 8(2): 1–15. DOI: 10.1007/s11947-014-1411-x

[39] Valverde JM, Giméneza MJ, Valero D, Martínez-Romero D, Serrano M: Methyl salicylate treatments of sweet cherry trees increase antioxidant systems in fruit at harvest and during storage. Postharvest Biology and Technology, 2015, **109**: 106–113. DOI: 10.1016/j.postharvbio.2015.06.011

[40] Kelebek H, Selli S: Evaluation of chemical constituents and antioxidant activity of sweet cherry (*Prunus avium* L.) cultivars. Journal of Food Science and Technology, 2011, **46**: 2530–2537. DOI: 10.1111/j.1365-2621.2011.02777.x

[41] Serra AT, Duarte RO, Bonze MR, Duarte CMM: Identification of bioactive response in traditional cherries from Portugal. Food Chemistry, 2011, **125**: 318–325. DOI: 10.1016/j.foodchem.2010.07.088

[42] Seeram NP, Momin RA, Nair MG, Bourquin LD: Cyclooxygenase inhibitory and antioxidant cyanidin glycosides in cherries and berries. Phytomedicine, 2001, **8**: 362–369. DOI: 10.1078/0944-7113-00053

[43] Kim DO, Heo HJ, Kim YJ, Yang HS, Lee CY: Sweet and sour cherry phenolics and their protective effects on neuronal cells. Journal of Agricultural and Food Chemistry, 2005, **53**: 9921–9927. DOI: 10.1021/jf0518599

[44] Matias AA, Rosado-Ramos R, Nunes LS, Figueira I, Serra AT, Bronze MR, Santos CN, Duarte C: Protective effect of a (poly)phenol-rich extract derived from sweet cherries culls against oxidative cell damage. Molecules, 2016, **21**: 1–16. DOI: 10.3390/molecules21040406

[45] Adisakwattana S, Yibchok-Anun S, Charoenlertkul P, Wongsasiripat N: Cyanidin-3-rutinoside alleviates postprandial hyperglycemia and its synergism with acarbose by inhibition of intestinal α-glucosidase. Journal of Clinical Biochemistry and Nutrition, 2011, **49**: 36–41. DOI: 10.3164/jcbn.10-116

[46] Xia M, Hou M, Zhu H, Ma J, Tang Z, Wang Q, Li Y, Chi D, Yu X, Zhao T, Han P, Xia X, Ling W: Anthocyanins induce cholesterol efflux from mouse peritoneal macrophages. The role of peroxisome proliferators-activated receptor Ó-Liver X Receptor α-ABCA1 Pathway. Journal of Biological Chemistry, 2005, **280**: 36792–36801. DOI: 10.1074/jbc.M505047200

[47] Srivastava A, Akoh CC, Fischer J, Krewer G: Effect of anthocyanin fractions from selected cultivars of Georgia-grown blueberries on apoptosis and phase II enzymes. Journal of Biological Chemistry, 2007, **55**: 3180–3185. DOI: 10.1021/jf062915o

[48] Vander Kloet SP, Dickinson TA: The taxonomy of *Vaccinium* section *Myrtillus* (*Ericaceae*). Brittonia, 1999, **51**: 231–254. DOI: 10.2307/2666632

[49] Routray W, Orsat V: Blueberries and their anthocyanins: factors affecting biosynthesis and properties. Comprehensive Reviews in Food Science and Food Safety, 2011, **10**: 303–320. DOI: 10.1111/j.1541-4337.2011.00164.x

[50] Martin RR, Polashock JJ, Tzanetakis E: New and emerging viruses of blueberry and cranberry. Viruses, 2012, **4**: 2831–2852. DOI: 10.3390/v4112831

[51] Liu RH: Health-promoting components of fruits and vegetables in the diet. Advances in Nutrition, 2013, **4**: 384S–392S. DOI: 10.3945/an.112.003517

[52] Villata M: Trends in world blueberry production. Available online: http://www.growingproduce.com/article/26272/trends-in-world-blueberry-production/2016 (accessed on 31 August 2016).

[53] US Department of Agriculture (USDA): 2016. Noncitrus Fruits and Nuts—2015 Summary. Available online: http://usda.mannlib.cornell.edu/usda/current/NoncFruiNu/NoncFruiNu-07-06-2016.pdf (accessed on 31 August 2016).

[54] Espin JC, Soler-Rivas C, Wichers HJ, Garcia-Viguera C: Anthocyanin-based natural colorants: a new source of antiradical activity for foodstuff. Journal of Agricultural and Food Chemistry, 2000, **48**: 1588–1592. DOI: 10.1021/jf9911390

[55] Stevenson D, Scalzo J: Anthocyanin composition and content of blueberries from around the world. Journal of Berry Research, 2012, **2**: 179–189. DOI: 10.3233/JBR-2012-038

[56] Nile SH, Park SW: Edible berries: bioactive components and their effect on human health. Nutrition, 2014, **30**: 134–144. DOI: 10.1016/j.nut.2013.04.007

[57] Yousef GG, Brown AF, Funakoshi Y, Mbeunkui F, Grace MH, Ballington JR, Loraine A, Lila MA: Efficient quantification of the health-relevant anthocyanin and phenolic acid profiles in commercial cultivars and breeding selections of blueberries (*Vaccinium* spp.). Journal of Agricultural and Food Chemistry, 2013, **61**: 4806–4815. DOI: 10.1021/jf400823s

[58] Huang WY, Liu YM, Wang J, Wang XN, Li CY: Anti-inflammatory effect of the blueberry anthocyanins malvidin-3-glucoside and malvidin-3-galactoside in endothelial cells. Molecules, 2014, **19**: 12827–12841. DOI: 10.3390/molecules190812827

[59] Borges G, Degeneve A, Mullen W, Crozier A: Identification of flavonoid and phenolic antioxidants in black currants, blueberries, raspberries, red currants, and cranberries. Journal of Agricultural and Food Chemistry, 2010, **58**: 3901–3909. DOI: 10.1021/jf902263n

[60] Cho MJ, Howard LR, Prior RL, Clark JR: Flavonoid glycosides and antioxidant capacity of various blackberry, blueberry and red grape genotypes determined by high-performance liquid chromatography/mass spectrometry. Journal of the Science of Food and Agriculture, 2004, **84**: 1771–1782. DOI: 10.1002/jsfa.1885

[61] Troszyñska A, Estrella I, Lamparski G, Hernández T, Amarowicz R, Pegg RB: Relationship between the sensory quality of lentil (*Lens culinaris*) sprouts and their phenolic constituents. Food Research International, 2011, **44**: 3195–3201. DOI: 10.1016/j.foodres.2011.08.007

[62] Blanda G, Cerretani L, Bendini A, Cardinali A, Scarpellini A, Lercker G: Effect of vacuum impregnation on the phenolic content of Granny Smith and Stark Delicious frozen apple cv. European Food Research and Technology, 2008, **226**: 1229–1237. DOI: 10.1007/s00217-007-0624-x

[63] Blanda G, Cerretani L, Cardinali A, Barbieri S, Bendini A, Lercker G: Osmotic dehydro-freezing of strawberries: polyphenolic content, volatile profile and consumer acceptance. LWT – Food Science and Technology, 2009, **42**: 30–36. DOI: 10.1016/j.lwt.2008.07.002

[64] Barrett DM, Beaulieu J, Shewfelt R: Color, flavor, texture, and nutritional quality of fresh-cut fruits and vegetables: desirable levels, instrumental and sensory measurement, and the effects of processing. Critical Reviews in Food Science and Nutrition, 2010, **50**: 369–389. DOI: 10.1080/10408391003626322.

[65] Kasım MU, Kasım R: Color quality of fresh-cut fruits and vegetables. Conference paper in the Sixth International Scientific Agricultural Symposium "Agrosym 2015", Jahorina, Bosnia and Herzegovina, October 15–18. Book of Proceedings, 2015, **47**: 1007–1014.

[66] El Gharras H: Polyphenols: food sources, properties and applications – a review. International Journal of Food Science and Technology, 2009, **44**: 2512–2518. DOI: 10.1111/j.1365-2621.2009.02077.x

[67] Just the Berries. What Are Blackcurrants? A Brief History of the World's Best Super-Fruit. Available online: http://jtbpd.com/information.php?information_id=1. 2013 (accessed on 22 August 2016).

[68] Cadot Y, Caillé S, Samson A, Barbeau G, Cheynier V: Sensory representation of typicality of Cabernet franc wines related to phenolic composition: impact of ripening stage and maceration time. Analytica Chimica Acta, 2012, **732**: 91–99. DOI: 10.1016/j.aca.2012.02.013

[69] Spence C: On the psychological impact of food colour. Flavour, 2015, **4**: 16. DOI: 10.1186/s13411-015-0031-3

[70] Piqueras-Fizman B, Spence C: Sensory expectations based on product-extrinsic food cues: an interdisciplinary review of the empirical evidence and theoretical accounts. Food Quality and Preference, 2015, **40**: 165–179. DOI: 10.1016/j.foodqual.2014.09.013

[71] Spence C: Multisensory flavour perception. Current Biology (special issue), 2013, **23**: R365–R369. DOI: 10.1016/j.cub.2013.01.028

[72] Gavrilova V, Kajdzanoska M, Gjamovski V, Stefova M: Separation, characterization and quantification of phenolic compounds in blueberries and red and black currants by HPLC-DAD-ESI-MSn. Journal of Agricultural and Food Chemistry, 2011, **59**: 4009–4018. DOI: 10.1021/jf104565y

[73] Honkanen E, Pyysalo T, Hirvi T: The aroma of Finnish wild raspberries, *Rubus idaeus*. Zeitschrift für Lebensmittel-Untersuchung und Forschung, 1980, **171**: 180–182. DOI: 10.1007/BF01042646

[74] Aprea E, Biasioli F, Gasperi F: Volatile compounds of raspberry fruit: from analytical methods to biological role and sensory impact (Review). Molecules, 2015, **20**: 2445–2474. DOI: 10.3390/molecules20022445

[75] Bravo L: Polyphenols: chemistry, dietary sources, metabolism, and nutritional significance. Nutrition Reviews, 1998, **56**: 317–333.

[76] Rouseff RL: Bitterness in food products: an overview. In: Bitterness in foods and beverages. Developments in Food Science, Rouoseff R.L., ed. 1990, 25. Amsterdam: Elsevier, pp. 1–14.

[77] Vilela A, Cosme F, Jordão AM: Wine phenolics: looking for a smooth mouthfeel (Review Article). SDRP Journal of Food Science &' Technology, 2015, **1**: 8.

[78] Soares S, Kohl S, Thalmann S, Mateus N, Meyerhof W, De Freitas V: Different phenolic compounds activate distinct human bitter taste receptors. Journal of Agricultural and Food Chemistry, 2013, **61**: 1525–1533. DOI: 10.1021/jf304198k

[79] Noble CA: Bitterness in wine. Physiology and Behavior, 1994, **56**: 1251–1255.

[80] Ma W, Guo A, Zhang Y, Wang H, Liu Y, Li H: A review on astringency and bitterness perception of tannins in wine. Trends in Food Science and Technology, 2014, **40**: 6–19. DOI: 10.1016/j.tifs.2014.08.001

[81] Preys S, Mazerolles G, Courcoux P, Samson A, Fischer U, Hanafi M, Bertrand D, Cheynier V: Relationship between polyphenolic composition and some sensory properties in red wines using multiway analyses. Analytica Chimica Acta, 2006, **563**: 126–136. DOI: 10.1016/j.aca.2005.10.082

[82] Quijada-Morin N, Regueiro J, Simal-Gandara J, Tomas E, Rivas-Gonzalo JC, Escribano-Bailon MT: Relationship between the sensory-determined astringency and the flavanolic composition of red wines. Journal of Agricultural and Food Chemistry, 2012, **60**: 12355–12361. DOI: 10.1021/jf3044346

[83] Adams DO: Phenolics and ripening in grape berries. American Journal of Enology and Viticulture, 2006, **57**: 249–256.

[84] Vidal S, Francis L, Guyot S, Marnet N, Kwiatkowski M, Gawel R, Cheynier V, Waters EL: The mouth-feel properties of grape and apple proanthocyanidins in a wine-like medium. Journal of the Science of Food and Agriculture, 2003, **83**: 564–573. DOI: 10.1002/jsfa.1394

[85] Peleg H, Gacon K, Schlich P, Noble AC: Bitterness and astringency of flavan-3-ol monomers, dimers and trimers. Journal of the Science of Food and Agriculture, 1999, **79**: 1123–1128. DOI: 10.1002/(SICI)1097-0010(199906)79:8<1123::AID-JSFA336>3.0.CO;2-D

[86] He M, Tian H, Luo X, Qi X, Chen X: Molecular progress in research on fruit astringency (Review). Molecules, 2015, **20**: 1434–1451. DOI:10.3390/molecules20011434

[87] Cardona FC, Andrés-Lacueva S, Tulipani F, Tinahones J, Queipo-Ortuño MI: Benefits of polyphenols on gut microbiota and implications in human health. Journal of Nutritional Biochemistry, 2013, **24**: 1415–1422. DOI: 10.1016/j.jnutbio.2013.05.001

[88] Marín L, Miguélez EM, Villar CJ, Lombó F: Bioavailability of dietary polyphenols and gut microbiota metabolism: antimicrobial Properties. BioMed Research International, 2015, **905215**: 18. DOI: 10.1155/2015/905215

[89] Mariat D, Firmesse O, Levenez F: The Firmicutes/Bacteroidetes ratio of the human microbiota changes with age. BMC Microbiology, 2009, **9**: 123. DOI: 10.1186/1471-2180-9-123

[90] Winter J, Moore LH, Dowell Jr VR, Bokkenheuser VD: C-ring cleavage of flavonoids by human intestinal bacteria. Applied and Environmental Microbiology, 1989, **55**: 1203–1208. DOI: 0099-2240/89/051203-06$02.00/0

[91] Krumholz LR, Bryant MP: *Eubacterium oxidoreducens* sp. nov. requiring H_2 or formate to degrade gallate, pyrogallol, phloroglucinol and quercetin. Archives of Microbiology, 1986, **144**: 8–14. DOI: 10.1007/BF00454948

[92] Schneider H, Simmering R, Hartmann L, Pforte H, Blaut M: Degradation of quercetin-3-glucoside in gnotobiotic rats, associated with human intestinal bacteria. Journal of Applied Microbiology, 2000, **89**: 1027–1037. DOI: 10.1046/j.1365-2672.2000.01209.x

[93] Rechner AR, Smith MA, Kuhnle G, Gibson GR, Debnam ES, Srai SKS, Moore KP, Rice-Evans CA: Colonic metabolism of dietary polyphenols: influence of structure on microbial fermentation products. Free Radical Biology and Medicine, 2004, **36**: 212–225. DOI: 10.1016/j.freeradbiomed.2003.09.022

[94] Monagas M, Urpi-Sarda M, Sanchez-Patán F, Gómez-Cordovés C, Andres-Lacuevab C, Bartolomé B: Insights into the metabolism and microbial biotransformation of dietary flavan-3-ols and the bioactivity of their metabolites. Food and Function, 2010, **1**: 233–253. DOI: 10.1039/C0FO00132E

[95] Tzounis X, Vulevic J, Kuhnle GGC, George T, Leonczak J, Gibson GR, Kwik-Uribe C, Spencer JPE: Flavanol monomer-induced changes to the human faecal microflora. British Journal of Nutrition, 2008, **99**: 782–792. DOI: 10.1017/S0007114507853384

[96] Schneider H, Blaut M: Anaerobic degradation of flavonoids by *Eubacterium ramulus*. Archives of Microbiology, 2000, **173**: 71–75.

[97] Yamakoshi J, Tokutake S, Kikuchi M, Kubota Y, Konishi H, Mitsuoka T: Effect of proanthocyanidin-rich extract from grape seeds on human fecal flora and fecal odor. Microbial Ecology in Health and Disease, 2001, **13**: 25–31. DOI: 10.3402/mehd.v13i1.7996

[98] Miladinović B, Kostić M, Šavikin K, Đordević B, Mihajilov-Krstev T, Živanović S, Kitić D: Chemical profile and antioxidative and antimicrobial activity of juices and extracts of 4 black currants varieties (*Ribes nigrum* L.). Journal of Food Science, 2014, **79**: C301–C309. DOI: 10.1111/1750-3841.12364

[99] Burdulis D, Sarkinas A, Jasutiené I, Stackevicené E, Nikolajevas L, Janulis V: Comparative study of anthocyanin composition, antimicrobial and antioxidant activity in bilberry (*Vaccinium myrtillus* L.) and blueberry (*Vaccinium corymbosum* L.) fruits. Acta Poloniae Pharmaceutica—Drug Research, 2009, **66**: 399–408.

[100] Gonthier MP, Remesy C, Scalbert A, Cheynier V, Souquet JM, Poutanen K, Aura AM: Microbial metabolism of caffeic acid and its esters chlorogenic and caftaric acids by human faecal microbiota in vitro. Biomedicine and Pharmacotherapy, 2006, **60**: 536–540. DOI: 10.1016/j.biopha.2006.07.084

[101] Andreasen MF, Kroon PA, Williamson G, Garcia-Conesa MT: Esterase activity able to hydrolyze dietary antioxidant hydroxycinnamates is distributed along the intestine of mammals. Journal of Agricultural and Food Chemistry, 2001, **49**: 5679–5684. DOI: 10.1021/jf010668c

[102] Couteau D, McCartney AL, Gibson GR, Williamson G, Faulds CB: Isolation and characterization of human colonic bacteria able to hydrolyse chlorogenic acid. Journal of Applied Microbiology, 2001, **90**: 873–881. DOI: 10.1046/j.1365-2672.2001.01316.x

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