

17 Fruit Chemistry, Nutritional Benefits and Social Aspects of Cherries

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17.1 Introduction

Cherry nutritional composition, phytochemical content and antioxidant capacity should be considered on a cultivar/genotype basis since many new cultivars that enter into the market through the breeding programmes (Sansavini and Lugli, 2008) have apparent differences for both qualitative and phytochemical antioxidants contents (Ballistreri *et al.*, 2013; Goulas *et al.*, 2015). The breeding programmes have led to the release of numerous cultivars, where the main attributes considered were bearing habits, ripening period, fruit size and yield, increased fertility, reduced susceptibility to environmental damage and diseases, extension of seasonality, especially for early-ripening genotypes, and resistance to cracking. However, to the best of our knowledge, phytochemical status and nutritional properties are not being evaluated through the breeding programmes.

This chapter focuses on the physicochemical characteristics (soluble solids, pH, titratable acidity, volatile compounds) and nutritional (e.g. carbohydrates, proteins,

lipids, sugars, organic acids, minerals, vitamins) and non-nutritional (other constituents with biological properties beyond nutrition) composition of sweet and sour cherry fruits. Non-nutrient food constituents include phytochemicals, phytonutrients, plant secondary metabolites, and bioactive and health-promoting compounds.

17.2 Fruit Chemistry

The chemical characteristics of sweet cherries (*Prunus avium* L.) and sour cherries (*Prunus cerasus* L.) have been widely reviewed, not only because they largely affect the sensory quality of the fruit, but also because they have a strong influence on consumer acceptance (Crisosto *et al.*, 2003). Furthermore, physicochemical studies are also relevant for producers for proper design of the harvesting and postharvest technology for sweet cherry production in the world (Hayaloglu and Demir, 2015). The large and diverse reported values of pomological characteristics of cherries denote how these

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properties are highly influenced not only by the cultivar, but also by other environmental variables, such as climatological conditions and geographical origin (Faniadis *et al.*, 2010; Tomás-Barberán *et al.*, 2013).

Both sweet and sour cherries present a very low caloric content: 63.0 kcal (263.34 kJ) per 100 g for sweet cherry and 50.0 kcal (209 kJ) per 100 g for sour cherry (USDA ARS, 2016). They are also considered an excellent source of numerous nutrients and phytochemicals (McCune *et al.*, 2011), which is one of the major reasons for their increasing popularity in the human diet. In addition, many epidemiological studies have established that their regular consumption is associated with health benefits and the well-being of individuals (Ferretti *et al.*, 2010; McCune *et al.*, 2011).

17.2.1 Total soluble solids

The value of total soluble solids (TSS) in sour and sweet cherries may reach up to 25.0 g per 100 g fresh weight (FW) (Table 17.1). This parameter is an important factor in determining the consumer's acceptability (Crisosto *et al.*, 2003; Valero and Serrano, 2010). For sweet cherry, reported values range

as low as 12.3 g per 100 g FW in 'Van' (González-Gómez *et al.*, 2010) to 24.5 g per 100 g FW in 'Salmo' (Girard and Kopp, 1998). Such differences in TSS can be attributed to microclimatic conditions, rootstock selection and planting system, as well as differences in the physiological stage adopted as a harvesting criterion (Goulas *et al.*, 2015). Finally, it has also been reported that TSS must be above the threshold of 14.0–16.0 g per 100 g FW as acceptable for marketing cherries (Crisosto *et al.*, 2003).

In the case of sour cherry, the average values found in commercial cultivars are around 15.0 g per 100 g FW, while only a few cultivars are above the threshold of 17.0 g per 100 g FW (Grafe and Schuster, 2014). Interestingly, autochthonous sour cherry genotypes in Portugal were found to have TSS values in the range 17.4–22.8 g per 100 g FW (Rodrigues *et al.*, 2008). Hungarian sour cherry cultivars also showed appreciably high levels of TSS (up to 23.1 g per 100 g FW in cultivar 'Pipacs 1') (Papp *et al.*, 2010).

17.2.2 Titratable acidity

Titrateable acidity (TA) is one of the most important attributes in cherry, since it is also

Table 17.1. Standard physicochemical attributes of sweet and sour cherries.

Species	TSS (mg per 100 g FW)		TA (g malic acid per 100 g FW)		Maturation index (TSS/TA)	
	References	References	References	References	References	References
Sweet cherry (<i>Prunus avium</i> L.)	12.3–24.5	Girard and Kopp (1998); González-Gómez <i>et al.</i> (2010)	0.7–1.2	Serradilla <i>et al.</i> (2016)	8.6–24.4	Usenik <i>et al.</i> (2010); Serradilla <i>et al.</i> (2012)
Sour cherry (<i>Prunus cerasus</i> L.)	15–23.1	Papp <i>et al.</i> (2010); Grafe and Schuster (2014)	1.3–3.1	Rodrigues <i>et al.</i> (2008); Papp <i>et al.</i> (2010); Rakonjac <i>et al.</i> (2010); Damar and Ekşi (2012); Grafe and Schuster (2014)	5.8–15.8	Wojdyło <i>et al.</i> (2014)

FW, fresh weight; TSS, total soluble solids; TA, titrateable acidity.

directly related to the acceptability by consumers, and it is a highly cultivar-dependent parameter. Sweet cherries are considered as mildly acidic fruits with pH values between 3.7 and 4.2, while sour cherries range from pH 3.1 to 3.6 (Serradilla *et al.*, 2016). Regarding TA, important differences have been observed between sweet and sour cherry and among cultivars. For sweet cherries, TA ranges from 0.7 to 1.2 g malic acid per 100 g FW (Table 17.1), with cultivars such as 'Lapins' showing low TA values, while 'Sweetheart' contains higher values. In the case of sour cherry, several studies reported a TA range of 1.4–2.9 g malic acid per 100 g FW (Damar and Ekşi, 2012). Grafe and Schuster (2014) found TA from 1.3 to 3.1 g malic acid per 100 g FW ('Spinell' and 'Topas', respectively). A similar range was determined in Portuguese (Rodrigues *et al.*, 2008), Hungarian (Papp *et al.*, 2010) and Serbian (Rakonjac *et al.*, 2010) germplasm collections.

17.2.3 Maturation index

The maturity index (TSS/TA ratio) is one of the major analytical measures of fruit quality, and it is widely accepted that it directly affects the perception of sweetness and flavour, and thus consumer acceptance of the cherry fruit (Crisosto *et al.*, 2003). In this sense, Guyer *et al.* (1993) observed that, as the TSS/TA ratio of cherry fruits increases, so does the consumer perception of sweetness. Compared with sweet cherry, sour cherry is characterized by a higher acidity level, resulting in lower TSS/TA ratios. For sweet cherry, reported values range between 19.0 in Turkish cultivars (Hayaloglu and Demir, 2015) to 29.0 in some Canadian sweet cherries (Girard and Kopp, 1998), while values around 40.0 have been monitored in certain cultivars (Usenik *et al.*, 2010; Serradilla *et al.*, 2012). For sour cherry, evaluation of the physicochemical composition of 33 sour cherries revealed a range in TSS/TA ratio from 5.8 to 15.3 (Wojdyło *et al.*, 2014), while in Hungarian cultivars it varied from 9.6 to 15.8 (Table 17.1). Cultivars with higher TSS/TA ratios (≥ 11.0), contributing

to a balanced flavour, have been considered an optimal choice for fresh consumption (Papp *et al.*, 2010). The new German cultivars 'Achat' (12.2) and 'Spinell' (14.8) (Schuster *et al.*, 2014) and the new Serbian cultivar 'Lenka' (17.7) (Fotirić Akšić *et al.*, 2015), resulting from different breeding programmes in Germany and Serbia, were particularly selected for fresh consumption due to their sweet sour cherry taste.

17.2.4 Volatile compounds

In terms of sensory quality, aroma and flavour are becoming key factors that determine the choice to purchase a fruit, although the compounds that contribute to the flavour of fresh fruit comprise only 0.001–0.01% of the fruit's fresh weight (Zhang *et al.*, 2007; Valero and Serrano, 2010). It is well known that the aroma of the fruit is the result of a complex mixture of esters, alcohols, aldehydes, ketones and terpenoid compounds (Li *et al.*, 2008; Valero and Serrano, 2010). In the case of cherries, their aroma has been studied extensively and comprises free and glycosidically volatile compounds (Girard and Kopp, 1998; Serradilla *et al.*, 2012; Wen *et al.*, 2014). Among the free volatile compounds, more than 100 have been identified such as hexanal, (E)-2-hexenal and benzaldehyde, which are among the predominant volatile flavour constituents in both sweet and sour cherries (Schmid and Grosch, 1986; Poll *et al.*, 2003; Serradilla *et al.*, 2016). In this sense, it has been reported that volatile compounds such as decanal, nonanal and (Z)-3-hexenal were identified as important odorants in 'Lapins', 'Rainier' and 'Stella' (Girard and Kopp, 1998). On the other hand, the aromatic carbonyl benzaldehyde has been determined at the highest level in sour cherry (Levaj *et al.*, 2010). Alcohols were the second largest class, including compounds such as benzyl alcohol, 1-hexanol and (E)-2-hexen-1-ol for sweet cherries. In contrast, according to Levaj *et al.* (2010), the alcohols identified in sour cherries, aside from 1-hexanol, were 1-butanol and 2-phenylethanol. Other compounds such as acids

have also been identified, mainly linear and branched acids, esters, monoterpenes (C10), sesquiterpenes (C15) and diterpenes (C20), in both sweet and sour cherries (Levaj *et al.*, 2010; Serradilla *et al.*, 2016). Aside from free volatile compounds, Wen *et al.* (2014) also reported that glycosidically bound aromatic compounds, integrated mainly by alcohols and terpenes, contribute markedly to the aroma of cherries.

17.3 Nutritional Composition

17.3.1 Water

Water is considered the predominant component of cherries, followed by carbohydrates, proteins and lipids (Serradilla *et al.*, 2016). The water content of sweet and sour cherry genotypes, as fleshy fruits, is around 80–83% (Serradilla *et al.*, 2016) and 81–88% (Filimon *et al.*, 2011), respectively. In general, the water content of sweet cherries is lower than that obtained from other stone fruits such as peaches with 88%, plums with 87% or apricots with 86% (USDA ARS, 2016).

17.3.2 Carbohydrates, proteins and lipids

Carbohydrates are the most abundant macronutrients found in cherries (Pacífico *et al.*, 2014; Bastos *et al.*, 2015). Although differences can be observed among cultivars, in general terms fruits exhibit moderate amounts of carbohydrates between 12.2 and 17.0 g per 100 g edible portion for sweet cherry, while sour cherry fruit has an average value of 12.2 g per 100 g edible portion (USDA ARS, 2016). In addition, within the genus *Prunus*, cherry fruit is a moderate source of dietary fibre, accounting for 1.3–2.1 g per 100 g edible portion (McCune *et al.*, 2011).

For sweet cherries, the protein content is between 0.8 and 1.4 g per 100 g edible portion (Serradilla *et al.*, 2016). However, for sour cherries, the protein content is below 1.0 g per 100 g edible portion (Ferretti *et al.*, 2010).

In general, the fat content of sweet and sour cherries is low and below 1.0 g per 100 g edible portion, particularly saturated fat as cherries are a cholesterol-free fruit (Ferretti *et al.*, 2010; McCune *et al.*, 2011; Pacifico *et al.*, 2014).

17.3.3 Sugars

Among these compounds, simple sugars (glucose, fructose, sucrose and sorbitol) are the most relevant (Usenik *et al.*, 2008, 2010; Serradilla *et al.*, 2011; Ballistreri *et al.*, 2013; Pacifico *et al.*, 2014), although trace amounts of sucrose were also identified in sweet cherries, ranging from 0.1 to 1.2 mg per 100 g FW (Esti *et al.*, 2002; Usenik *et al.*, 2008; Ballistreri *et al.*, 2013). The major sugar in sweet and sour cherries is glucose, whose range varies from 6.0 to 10.0 g per 100 g FW, depending on the genotype and environmental conditions (Papp *et al.*, 2010; Ballistreri *et al.*, 2013). The second most abundant sugar is fructose. Its content ranges from 5.0 to 7.6 g per 100 g FW for sweet cherry and from 3.5 to 4.9 g per 100 g FW for sour cherry (Papp *et al.*, 2010; Ballistreri *et al.*, 2013). In fact, in both cases, these authors reported that the genotypes with a higher glucose content had also a higher fructose level. Aside from glucose and fructose, the content of sorbitol for sweet cherries ranged between 0.9 and 26.7 mg per 100 g FW, showing quantities similar to other fruits such as apples, pears, peaches and prunes (Usenik *et al.*, 2008; Ballistreri *et al.*, 2013).

17.3.4 Organic acids

The type of organic acid is an important factor in determining fruit acidity (Valero and Serrano, 2010), with malic acid being the principal organic acid in cherries, with values of 360.0–1277.0 mg per 100 g FW, accounting for more than 98% of the total organic acid content. It is also possible to find, as minor constituents, citric, succinic, shikimic, fumaric and oxalic acids (Usenik

et al., 2008; Ballistreri *et al.*, 2013; Serradilla *et al.*, 2016). Additionally, Ballistreri *et al.* (2013) found a high correlation between the total content of organic acids and TA levels in sweet cherry, reflecting the influence of the different content of organic acids on TA.

17.3.5 Minerals

Sweet cherry is considered to be a good source of dietary potassium with approximately 260.0 mg potassium per 100 g edible portion (McCune *et al.*, 2011). For sour cherry, potassium is also the main mineral with 200.0 mg per 100 g edible portion. Cherries also contain other minerals in low concentrations such as calcium, phosphorous, magnesium and sodium (USDA ARS, 2016). In sweet cherries, calcium concentration ranged between 13.0 and 20.0 mg per 100 g edible portion, while phosphorous levels varied between 15.0 and 18.0 mg per 100 g edible portion, magnesium between 8.0 and 13.0 mg per 100 g edible portion, and sodium between 1.0 and 8.0 mg per 100 g edible portion. Sour cherries showed a content of calcium that ranged between 9.0 and 14.0 mg per 100 g edible portion, magnesium between 7.0– and 10.0 mg per 100 g edible portion, and phosphorous between 9.0 and 20.0 mg per 100 g edible portion (Mitić *et al.*, 2012; USDA ARS, 2016).

17.3.6 Vitamins

Cherries are an excellent source of vitamins, especially vitamin C (7.0–50.0 mg per 100 g edible portion), followed by vitamin E (0.1 mg per 100 g edible portion) and vitamin K (2.0 µg per 100 g edible portion) (McCune *et al.*, 2011). In addition, sour cherries are characterized by a higher content of vitamin A (64.0 mg of retinol activity equivalent (RAE) per 100 g edible portion), whereas the vitamin A content in sweet cherries is around 3.0 mg RAE per 100 g edible portion (Serradilla *et al.*, 2016).

17.4 Phytochemical Composition and Antioxidant Activity

17.4.1 Carotenoids

Carotenoids are the most widely distributed group of pigments naturally accumulating in large quantities, and are known for their structural diversity and various functions, including the brilliant red, orange and yellow colours of edible fruits (Valero and Serrano, 2010). Within the major phytochemicals found in sweet cherries are carotenoids (β -carotene, lutein, α -carotene, β -cryptoxanthin, zeaxanthin and phytoene). Sweet cherries contain important amounts of carotenoids, mainly β -carotene (38.0 µg per 100 g FW) and lutein/zeaxanthin (85.0 µg per 100 g FW) (Tomás-Barberán *et al.*, 2013). Sour cherries contain some carotenoids, in particular β -carotene (770.0 µg per 100 g FW), and to a lower extent lutein and zeaxanthin (85.0 µg per 100 g FW) (Ferretti *et al.*, 2010).

17.4.2 Phenolic compounds

Phenolic compounds, as well as their health-promoting properties, also play a key role in cherry quality attributes since they contribute to colour, taste, aroma and flavour (Tomás-Barberán and Espín, 2001). Despite its significant economic impact as a temperate fruit crop, few comprehensive studies have dealt with physicochemical and phytochemical aspects of different cultivars (Ballistreri *et al.*, 2013). Most of these studies have focused on analyses solely at harvest time, although alterations in the phytochemical content during the postharvest period have also been reported (Valero *et al.*, 2011).

Cherry polyphenols include phenolic acids (hydroxycinnamic and hydroxybenzoic acids) and flavonoids (anthocyanins, flavonols and flavan-3-ols) (Fig. 17.1). Those secondary metabolites are involved in anti-oxidative defence of plants against biotic and abiotic stresses such as high and low temperatures, drought, alkalinity, salinity,

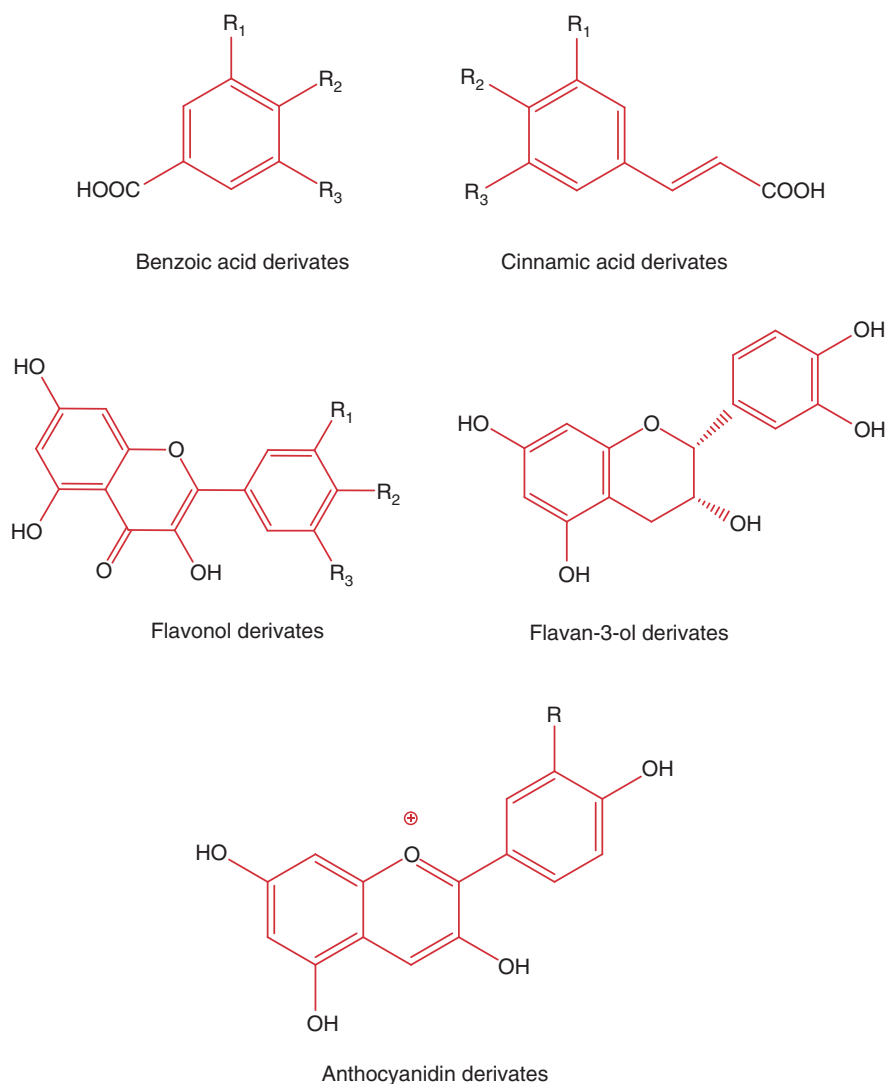


Fig. 17.1. The main phytochemical compounds present in sweet and sour cherries. (Drawn using ChemDraw Ultra v.12.0, CambridgeSoft®.)

UV stress and pathogen attack (Viljevac *et al.*, 2012). The highest levels of total polyphenolic compounds are found in the skin of cherry fruits, followed by the flesh and pit (Chaovanalikit and Wrolstad, 2004). Current epidemiological studies strongly support a contribution of polyphenols in the prevention of cardiovascular diseases, cancers, diabetes, insomnia, obesity and osteoporosis, as well as neurodegenerative

diseases (Kang *et al.*, 2003; Kim *et al.*, 2005; Pigeon *et al.*, 2010).

A wide range of concentrations of total phenolic content (TPC) has been reported both in sweet and sour cherries (Ballistreri *et al.*, 2013; Tomás-Barberán *et al.*, 2013; Serradilla *et al.*, 2016). The most important results for both species are represented in Table 17.2, which show that sour cherry exhibits higher TPC than sweet cherry.

Table 17.2. Total phenolic content of sweet and sour cherries. Data are expressed on a fresh weight (FW) or dry weight basis (DW).

Species	Total phenolic content		References
	(mg per 100 g FW)	(mg per 100 g DW)	
Sweet cherry (<i>Prunus avium</i> L.)	44.3–192.0	440.0–1309.0	Usenik <i>et al.</i> (2008); Serra <i>et al.</i> (2011); Ballistreri <i>et al.</i> (2013); Tomás-Barberán <i>et al.</i> (2013)
Sour cherry (<i>Prunus cerasus</i> L.)	74.0–754.0	1539.0–2983.0	Kim <i>et al.</i> (2005); Bonerz <i>et al.</i> (2007); Dragović-Uzelac <i>et al.</i> (2007); Kirakosyan <i>et al.</i> (2009); Khoo <i>et al.</i> (2011); Wojdyło <i>et al.</i> (2014); Alrgei <i>et al.</i> (2016)

Phenolic acids

Phenolic acids or phenolcarboxylic acids are types of aromatic secondary plant metabolites, widely spread throughout the plant kingdom. They contribute to food quality and organoleptic properties, and they belong to two subgroups: the hydroxybenzoic and the hydroxycinnamic acids.

Small amounts of hydroxybenzoic acids have been found in sweet cherries (Mattila *et al.*, 2006). With respect to sour cherry, Díaz-García *et al.* (2013) found gallic acid, 3,4-dihydroxybenzoic acid and vanillic acid, in accordance with the results of Chaovana-likit and Wrolstad (2004).

In contrast to hydroxybenzoic acid content, sweet cherries are rich in derivatives of hydroxycinnamic acids, which are the dominant polyphenols in sweet cherry fruit (Tomás-Barberán *et al.*, 2013; Martínez-Esplá *et al.*, 2014). The major hydroxycinnamic acids in sweet cherry are neochlorogenic and *p*-coumaroylquinic acid, followed by chlorogenic acid (Serradilla *et al.*, 2016). According to Mozetič *et al.* (2006), the ratio of neochlorogenic acid to *p*-coumaroylquinic acid is characteristic of each sweet cherry cultivar. Additionally, regarding neochlorogenic acid content, sweet cherry cultivars can be classified into three groups, the first group ranging between 40.0 and 128.0 mg per 100 g (e.g. 'Bing'), the second group between 20.0 and 40.0 mg per 100 g FW (e.g. '0900 Ziraat') and the third group ranging from 4.0 to 20.0 mg per 100 g FW (e.g. 'Sweetheart') (Ballistreri *et al.*, 2013). On the other hand, *p*-coumaroylquinic acid content

ranges from 0.8 to 131.0 mg per 100 g FW (Table 17.3) (Serradilla *et al.*, 2016). Currently, this acid is increasingly receiving attention for its health-promoting potential due to its ability to inhibit low-density lipoprotein (Tomás-Barberán *et al.*, 2013). Finally, Ballistreri *et al.* (2013) reported that chlorogenic acid concentrations in 24 sweet cherry cultivars were between 0.2 and 8.7 mg per 100 g FW.

Regarding sour cherry cultivars, the hydroxycinnamic acids found in cultivars 'Erdi Botermo' and 'Aode' grown in Chinese agroecological conditions were neochlorogenic acid, 4-coumaroylquinic acid, caffeoylquinic acid, chlorogenic acid and 3',5'-dicafeoylquinic acid (Cao *et al.*, 2015), where neochlorogenic and chlorogenic acid were dominant. An earlier study (Kim *et al.*, 2005) showed that the amount of chlorogenic acid in sour cherries was between 0.6 and 5.8 mg per 100 g FW, while neochlorogenic acid ranged from 6.7 to 27.8 mg per 100 g FW.

Similarly, Wojdyło *et al.* (2014) determined that in almost all 33 studied sour cherry cultivars studied, neochlorogenic acid (~47%) was the major hydroxycinnamic acid derivative, followed by chlorogenic acid (~30%) and *p*-coumaroylquinic acid (~19%). In 'Oblačinska' sour cherry clones, chlorogenic acid, the most widespread natural plant dietary antioxidant, varied from 0.8 to 3.7 mg per 100 g FW (Alrgei *et al.*, 2016). Levaj *et al.* (2010) determined the derivatives of caffeic, *p*-coumaric and chlorogenic acid in both 'Maraska' and 'Oblačinska' sour cherry cultivars (Fig. 17.2).

Table 17.3. Standard phytochemical attributes of sweet and sour cherries.

Species	Anthocyanins		Hydroxycinnamic acids		Flavonols		Flavan-3-ols		References
	CY 3-O-GLU	Cy-3 O-RUT	NCHL	PCQ	QUER	EPIC	QUER	EPIC	
Sweet cherry (<i>Prunus avium</i> L)	0.1–35.0 ^a	2.0–243.0 ^a	4.0–128.0 ^a	0.8–131.0 ^a	2.0–6.0 ^a	0.4–14.8 ^a	Ballistreri <i>et al.</i> (2013); Serradilla <i>et al.</i> (2016)	Usenik <i>et al.</i> (2008); González-Gómez <i>et al.</i> (2010)	Usenik <i>et al.</i> (2008); González-Gómez <i>et al.</i> (2010)
Sour cherry (<i>Prunus cerasus</i> L)	0.9–1.3 ^a	9.5–17.1 ^a	9.4–12.6 ^a		0.03–0.8 ^a	18.0–283.0 ^b	Mitić <i>et al.</i> (2012)	Wojdyło <i>et al.</i> (2014)	Wojdyło <i>et al.</i> (2014)
	2.0–9.9 ^c	35.4–85.5 ^c	212.0–998.0 ^c	191.0–999.0 ^c			Bonerz <i>et al.</i> (2007)		
	10.1 ^c	93.0 ^c					Damar and Ekşi (2012)		

CY 3-O-GLU, cyanidin 3-O-glucoside; CY 3-O-RUT, cyanidin 3-O-rutinoside; NCHL, neochlorogenic acid; PCQ, *p*-coumaroylquinic acid; QUER, quercetin; EPIC, epicatechin.

^amg per 100 g FW.

^bmg per 100 g DW.

^cmg l⁻¹ of juice.



Fig. 17.2. Sour cherries (cultivar 'Oblačinska').

Flavonoids

The flavanoids or bioflavonoids are a class of plant secondary metabolites. They include anthoxanthins (flavones and flavonols), flavanones, flavanonols, flavans and anthocyanidins. They play a role in protection against UV radiation, as well as being natural pigments, enzyme inhibitors, and precursors of toxic substances, flavour components and antioxidants, and they also provide resistance to pathogens (Piccolella *et al.*, 2008). Their functionality in human health has been proved in numerous studies suggesting protective effects against cardiovascular diseases, cancers and other age-related diseases (Yao *et al.*, 2004). The main flavonoids present in cherries are provided below.

ANTHOCYANINS. The common anthocyanidins, which are responsible for the attractive colour of cherries, are cyanidin, pelargonidin, peonidin, delphinidin, petunidin and malvidin (Valero and Serrano, 2010). For their quantitative and qualitative analysis, the main methodology used has been the technique of high-performance liquid chromatography (HPLC) coupled to a diode array detector (DAD) or a single quadrupole mass spectrometer equipped with an atmospheric pressure electrospray ionization source (API-ES-MS) (González-Gómez *et al.*, 2010; Serra *et al.*, 2011). Anthocyanins such as cyanidin 3-*O*-rutinoside, cyanidin 3-*O*-glucoside, peonidin 3-*O*-rutinoside and pelargonidin 3-*O*-rutinoside have been reported in

sweet cherries (Gonçalves *et al.*, 2004; González-Gómez *et al.*, 2010). However, Tomás-Barberán *et al.* (2013) and Serradilla *et al.* (2016) reported that cyanidin 3-*O*-rutinoside and cyanidin 3-*O*-glucoside are the predominant anthocyanins in sweet cherries.

For sweet cherries, total anthocyanin content ranges from a few milligrams per 100 g FW in light-coloured (score of 3 on the CTIFL colour chart) to about 300 mg per 100 g FW in dark cherries (score of 5) (Gao and Mazza, 1995; Wang *et al.*, 1997; Valero and Serrano, 2010). In general, light-coloured and dark-coloured red sweet cherry cultivars contain cyanidin 3-*O*-rutinoside (2.0–243.0 mg per 100 g FW) and cyanidin 3-*O*-glucoside (0.1–35.0 mg per 100 g FW) (Table 17.3), as the primary and secondary anthocyanin, respectively (Gao and Mazza, 1995; Usenik *et al.*, 2008; Ballistreri *et al.*, 2013).

The total anthocyanin content of sour cherries was reported to be between 27.8 and 80.4 mg per 100 g FW (Blando *et al.*, 2004). However, total anthocyanin content and the anthocyanin fractions differ according to the sour cherry cultivar (Wang *et al.*, 1997; Kim *et al.*, 2005; Simunic *et al.*, 2005). Several 'Oblačinska' clones, studied by Alrgei *et al.* (2016), showed substantial levels of total anthocyanin content (over 100.0 mg cyanidin 3-*O*-glucoside per 100 g FW). Several types of anthocyanin compounds were also determined in sour cherries by HPLC-DAD/API-ES-MS, but the most prevalent were those that are derivatives of cyanidin (cyanidin 3-*O*-glucosylrutinoside, cyanidin 3-*O*-sophoroside, cyanidin 3-*O*-rutinoside, cyanidin 3-*O*-glucoside, cyanidin 3-*O*-xylosylrutinoside and cyanidin 3-*O*-arabinosylrutinoside) (Blando *et al.*, 2004; Chaovana-likit and Wrolstad, 2004; Kim *et al.*, 2005; Bonerz *et al.*, 2007; Cao *et al.*, 2015). According to Kirakosyan *et al.* (2009), total cyanidins in 'Montmorency' cherries are about 93% of total anthocyanins, while in Balaton™ (syn. 'Ujfehertoi Furtos') they are about 94%. Finally, Mulabagal *et al.* (2009) reported that the cultivars 'Montmorency' and 'Batalon' are characterized by exhibiting cyanidin 3-*O*-glucosylrutinoside and cyanidin 3-*O*-rutinoside at a ratio of 3/1.

Peonidin 3-*O*-rutinoside, peonidin- 3-*O*-glucoside and pelargonidin 3-*O*-glucoside were also found in sour cherry fruit but in much lower concentration (Kirakosyan *et al.*, 2009), while the Hungarian sour cherry cultivars included in the study of Ficzek *et al.* (2011) showed very low concentrations of delphinidin. Jakobek *et al.* (2009) quantified the content of cyanidin 3-*O*-rutinoside (56.9 mg per 100 g FW), cyanidin 3-*O*-glucosylrutinoside (940.1 mg per 100 g FW), cyanidin 3-*O*-sophoroside (18.6 mg per 100 g FW) and cyanidin 3-*O*-glucoside (7.0 mg per 100 g FW).

Recently, the sweet cherry fruit nutritional profile has been monitored using an array of instrumental techniques, including spectrophotometric assays, HPLC and nuclear magnetic resonance (NMR) (Goulas *et al.*, 2015). In particular, NMR spectroscopy allows a rapid screening of specific primary and secondary metabolites of sweet cherries; Goulas *et al.* (2015) showed that the resonance of H-4 can be used to discriminate anthocyanins in fruit extracts as it appears at 8.2–8.6 p.p.m., a non-overcrowded region of the spectrum. The resonance of H-4 is dependent on the substitution of the anthocyanin skeleton and the discrimination of anthocyanins in a complex mixture is feasible. In a subsequent step, cyanidin 3-*O*-rutinoside was used to study the effect of pH on the chemical shift of H-4. The data indicated that the chemical shift of the diagnostic peak (H-4) is strongly influenced by pH, highlighting the need for pH adjustment of the sample. Finally, a pH value of 3.0 was selected to obtain ¹H-NMR spectra, since a sharp peak of H-4 was recorded and it is also the nearest pH to the actual pH of sweet cherry fruit at harvest (Goulas *et al.*, 2015).

The fact that cherries contain significant levels of anthocyanins has attracted much attention. One of the best-known properties of anthocyanins in general is their strong antioxidant activity in metabolic reactions, due to their ability to scavenge oxygen free radicals and other reactive species. Likewise, Wang *et al.* (1999) reported that sour cherry anthocyanins have an anti-inflammatory effect in cases of rheumatoid arthritis. Seeram *et al.* (2001) found that anthocyanins

originating from sour cherries have an inhibitory effect on COX-1 and COX-2 enzymes, which trigger inflammation, offering some protection against colon cancer (Kang *et al.*, 2003) and against type II diabetes by increasing insulin excretion (Jayaprakasam *et al.*, 2005). Studies have shown that numerous factors such as harvest season, variety, stage of harvesting, climatic conditions and growing season can affect the composition and concentration of individual as well as total anthocyanins (Sass-Kiss *et al.*, 2005).

FLAVONOLS. Flavonols are very important bioactive compounds, crucial for human health (Knekt *et al.*, 2000). A total of six flavonols have been quantified in sweet cherry fruit, with quercetin being the predominant one, fluctuating from 2.0 to 6.0 mg per 100 g FW (Table 17.3) (Usenik *et al.*, 2008; Bastos *et al.*, 2015; Serradilla *et al.*, 2016). This compound has been reported to have a great ability to act as a free-radical scavenger and therefore is associated with the prevention of degenerative diseases caused by oxidative stress, such as cardiovascular disease and cancer (Tomás-Barberán *et al.*, 2013).

In sour cherry, Kirakosyan *et al.* (2009) claimed quercetin, kaempferol and isorhamnetin rutinoside to be the main flavonol compounds. Levaj *et al.* (2010) showed that both quercetin and kaempferol were present in ‘Maraska’ (5.4 and 3.0 mg per 100 g FW, respectively) and ‘Oblačinska’ sour cherry (3.8 and 1.3 mg per 100 g FW, respectively). The same flavonols in sour cherry were determined by Jakobek *et al.* (2007), Piccolella *et al.* (2008), Ferretti *et al.* (2010) and Liu *et al.* (2011). In addition, Alrgei *et al.* (2016) determined the quantities of myricetin, pinobanksin and galangin in specific ‘Oblačinska’ sour cherry clones.

FLAVAN-3-OLS. In cherries, (+)-catechin and (–)-epicatechin are the main flavan-3-ols identified (Serra *et al.*, 2011). Cherry fruit stores flavan-3-ols in much lower amounts than the rest of the polyphenols. In general, for sweet cherry, (–)-epicatechin contents are higher than (+)-catechin, ranging from 0.4 mg per 100 g FW (‘Lapins’) to 15.0 mg

per 100 g FW ('Larian') (Usenik *et al.*, 2008; González-Gómez *et al.*, 2010). With respect to (+)-catechin, concentrations range from 2.9 mg per 100 g FW ('0900 Ziraat') to 9.0 mg per 100 g FW ('Noir de Guben') (Kellebek and Selli, 2011). The levels of these two compounds have been reported to be greatly influenced by agronomic and environmental conditions, as well as by genotype (Serradilla *et al.*, 2016).

For sour cherry, Usenik *et al.* (2010) reported the existence of procyanidin B2 and procyanidin dimer. As stated by Wojdyło *et al.* (2014) in a study with 33 sour cherry cultivars, procyanidin B1, procyanidin dimer, procyanidin trimer and procyanidin tetramer were found, and together ranged from 403.6 to 1215.7 mg per 100 g dry weight (DW). Besides procyanidins, Levaj *et al.* (2010) also found (+)-catechin, (–)-epicatechin and (+)-gallocatechin as monomers in both 'Maraska' and 'Oblačinska' sour cherry, which is in agreement with similar identification by Tsanova-Savova *et al.* (2005) and Chaovanalikit and Wrolstad (2004). As reported by Wojdyło *et al.* (2014), concentrations of (–)-epicatechin ranged from 18.0 to 283.0 mg per 100 g DW and of (+)-catechin from 4.0 to 116.0 mg per 100 g DW in 33 sour cherry cultivars. The highest monomer levels were found in 'Dradem', 'Meteor Korai' and 'Winer' fruits, while the lowest were found in 'Wanda', 'Lucyna' and 'Wifor' fruits. In contrast, catechin (1.4–1.6 mg per 100 g FW) is the only flavan-3-ol found in 'Erdi Bottermo' and 'Aode' (Cao *et al.*, 2015) grown in China. In one study, no flavan-3-ols were reported in sour cherry cultivars (Kim *et al.*, 2005).

17.4.3 Indolamines

The indolamine melatonin (MLT; *N*-acetyl-5-methoxytryptamine) is an endogenous hormone found to be present in all vertebrates (Reiter, 1993). MLT is synthesized from tryptophan via 5-hydroxytryptophan, serotonin and *N*-acetylserotonin in the vertebrate pineal gland (Fig. 17.3). MLT has been shown to possess a great number of health benefits (Reiter *et al.*, 1997). The

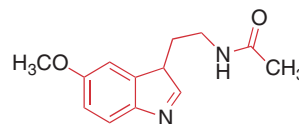


Fig. 17.3. The chemical structure of melatonin (*N*-acetyl-5-methoxytryptamine).

most well-known function of MLT in mammals is regulation of the sleep–wake cycle (Baker and Driver, 2007). Its other functions in humans range from sexual maturation to depression and antioxidative defence (Macchi and Bruce, 2004). As well as these properties, MLT has been reported to be a potent free-radical scavenger and a broad-spectrum antioxidant (Hardeland *et al.*, 2006). In addition, MLT detoxifies a variety of free radicals and reactive oxygen intermediates, including the hydroxyl radical, peroxy nitrite anion, singlet oxygen and nitric oxide.

The presence of MLT is not restricted to the animal kingdom. This indolamine is also found in a wide variety of plants and fruits (Feng *et al.*, 2014). The MLT biosynthetic route starts with the primary metabolite shikimate; this metabolite serves as the precursor of tryptophan, which through different metabolic pathways concludes in the synthesis of melatonin (Kurkin, 2003). MLT consumed in plant products is absorbed, enters the circulation and has physiological effects via receptor- or non-receptor-mediated processes. A number of reports are available describing the positive health effects of MLT intake from cherry derivatives (Garrido *et al.*, 2009, 2012, 2013; Zhao *et al.*, 2013).

In recent years, there has been particular interest in determining and quantifying the presence of MLT in different cherry species and cultivars, since the abundance of MLT in cherries is strongly correlated with the species and fruit cultivar, and some research also indicates that MLT abundance is related to fruit maturity (Burkhardt *et al.*, 2001; González-Gómez *et al.*, 2009; Kirakosyan *et al.*, 2009). The data shown in Table 17.4 highlight the significantly higher amounts of MLT found in sour cherries.

Table 17.4. Melatonin concentrations reported for different sweet and sour cherry cultivars. Results are expressed as ng g⁻¹ dry weight (DW).

Species	Cultivar	Amount reported (ng g ⁻¹ DW)	Reference
Sweet cherry (<i>Prunus avium</i> L.)	'Burlat'	0.2	González-Gómez <i>et al.</i> (2009)
	'Sweetheart'	0.1	González-Gómez <i>et al.</i> (2009)
	'Pico Negro'	0.12	González-Gómez <i>et al.</i> (2009)
	'Navalinda'	0.03	González-Gómez <i>et al.</i> (2009)
	'Van'	0.01	González-Gómez <i>et al.</i> (2009)
	'Ambrunés'	0.1	González-Gómez <i>et al.</i> (2009)
Sour cherry (<i>Prunus cerasus</i> L.)	'Pico Colorado'	0.1	González-Gómez <i>et al.</i> (2009)
	'Montmorency'	5.6–19.6	Burkhardt <i>et al.</i> (2001)
	'Montmorency'	12.3	Kirakosyan <i>et al.</i> (2009)
	Balaton ^{TMa}	1.1–2.2	Burkhardt <i>et al.</i> (2001)
	Balaton ^{TMa}	2.9	Kirakosyan <i>et al.</i> (2009)

^aSyn. 'Ujfehertoi Furtos'.

17.4.4 Antioxidant activity

Antioxidant activity has been widely investigated using different methodological approaches. In cherry, antioxidant potential has been associated with ascorbic acid, phenols and anthocyanins (Chaovanalikit and Wrolstad, 2004; Serrano *et al.*, 2005, 2009). In addition, cherries are characterized by the total antioxidant activity (TAA) in both hydrophilic and lipophilic fractions by measuring the scavenging capacity of 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) radicals (ABTS^{•+}) (Tomás-Barberán *et al.*, 2013). For sweet cherries, it has been reported that dark-coloured cultivars, such as 'Sonata', exhibited higher concentrations in both fractions compared with light-coloured cultivars, such as 'Brooks'. In addition, for all cultivars, hydrophilic TAA is higher than lipophilic TAA, showing that polyphenols or hydrophilic compounds are the major contributors to antioxidant activity (Tomás-Barberán *et al.*, 2013). According to Ballistreri *et al.* (2013), the TAA of 24 sweet cherry cultivars ranged from 646.0 to 3166.0 μmol Trolox equivalents (TE) per 100 g FW.

The total antioxidant capacity of 34 sour cherries was determined as between 900.0 and 6300.0 μmol TE per 100 g FW using an ABTS assay, where 'Fanal' and 'Heimanns' exhibited strong antioxidant capacity (Khuo *et al.*, 2011). As determined by Wojdyło

et al. (2014), the antioxidant activity of 33 sour cherry cultivars, evaluated using an oxygen radical absorbance capacity (ORAC) assay, was 8130.0–38,110.0 μmol TE 100 g DW. Among Hungarian sour cherry cultivars, 'Pipacs 1' presented an outstanding antioxidant capacity (21,850.0 μmol ascorbic acid l⁻¹), given the fact that it is an amarelle-type sour cherry with yellowish fruit flesh, and hence with an appreciably low anthocyanin content (Papp *et al.*, 2010). Tsuda *et al.* (1994) demonstrated that cyaniding 3-*O*-glucoside shows very strong antioxidant activity. According to Heinonen *et al.* (1998), using liposomes as model membranes, anthocyanins (especially malvidin with strong antioxidant activity and cyanidin, delphinidin and pelargonidin, which have pro-oxidant activity) and hydroxycinnamates isolated from sweet cherries are more active compared with those from other berries (e.g. blackberries, red raspberries, blueberries or strawberries).

17.5 Preharvest Factors Affecting Quality and Nutritional Compounds

Sweet cherry fruit is of prime importance worldwide with high commercial acceptability. However, sweet cherry is highly perishable after harvest; therefore, advanced fast precooling followed by cold storage is a

necessary postharvest tool to maintain fruit quality until consumption (Manganaris *et al.*, 2007). As mentioned earlier, the main factors determining the consumer's acceptability are TSS, acidity and colour (Crisosto *et al.*, 2003). Producers use a number of parameters to establish the optimum time for harvesting, the most reliable being skin colour (Romano *et al.*, 2006). Red colour development in sweet cherry is used as an indicator of quality and ripening, and is due to the accumulation and profile of anthocyanins (Díaz-Mula *et al.*, 2009). In addition, as mentioned earlier, in recent studies, an inverse association between fruit and vegetable intake and chronic diseases, such as different types of cancer and cardiovascular diseases, has been demonstrated in numerous epidemiological studies in which phytochemicals have been indicated to be responsible for this observed protective effect (Schreiner and Huyskens-Keil, 2006). Among these compounds, special interest has been focused on anthocyanins and other polyphenolics, carotenoids and vitamins C and E.

Consumer choice and preference for sweet cherries is influenced mainly by factors such as convenience, culture, price, appearance, taste and, in recent years, also their nutrient value and content of bioactive compounds. Accordingly, there are different preharvest factors that influence the content of bioactive compounds at the time of harvest, the most important being cultivar, temperature and light intensity, ripening stage at harvest and some preharvest treatments such as salicylate derivatives, oxalic acid and abscisic acid.

17.5.1 Influence of cultivar

Differences in phenolic contents were found among cultivars, with concentrations ranging between 98.0 and 200.0 mg per 100 g FW (Díaz-Mula *et al.*, 2008). 'Brooks' cherry has the lowest anthocyanin content (40.0 mg per 100 g), while 'Cristalina' shows the highest (225.0 mg per 100 g FW). The main phenolic compounds in sweet cherry fruits are anthocyanins, which also differed in concentration depending on cultivar.

Those cultivars with the lowest anthocyanins ('Brooks', 'Somerset', 'Prime Giant' and 'Sweetheart') are considered as light-coloured cultivars (score of 3 on the CTIFL colour chart), while those with the highest anthocyanin content ('Cristalina' and 'Sonata') are classified as dark-coloured (score of 5), showing a direct relationship between colour parameters and anthocyanin concentration (Díaz-Mula *et al.*, 2008). The most abundant phenolic acids in sweet cherry are derivatives of hydroxycinnamic acid such as caffeic acid and *p*-coumaric acid. The most common colourless phenolics in sweet cherries are neochlorogenic acid (3'-caffeilquinic acid) and *p*-coumaroylquinic acid (Mozetić *et al.*, 2002; Chaovanalikit and Wrolstad, 2004). The hydroxycinnamates are increasingly receiving attention for their potential health-promoting effects through their potent antioxidant action, their ability to inhibit low-density lipoprotein oxidation, and their chemopreventative properties (e.g. inhibitory effects on tumour promotion and the ability to block the formation of mutagenic compounds such as nitrosamines), as demonstrated by *in vitro* studies (Boots *et al.*, 2008; McCune *et al.*, 2011). The ability of phenolics to act as a free-radical scavengers suggests that they could play a beneficial role in reducing reactive oxygen species (i.e. hydrogen peroxide, superoxide anion) associated with chronic diseases such as cardiovascular disease and cancer (Wilms *et al.*, 2005). Sweet cherry cultivars have a considerable influence on the antioxidant capacity in both hydrophilic and lipophilic extracts as measured by the scavenging capacity of ABTS^{•+} radicals. According to Díaz-Mula *et al.* (2008), hydrophilic TAA is usually higher than lipophilic TAA for all studied cultivars (~80% of TTA in 'Cristalina' and ~50% in 'Prime Giant'), showing that the major contributors to antioxidant activity are hydrophilic compounds, such as polyphenols and anthocyanins. Antioxidant vitamins, such as tocopherols, and carotenoids are lipophilic compounds that might contribute to lipophilic TAA.

According to the National Cancer Institute (2004), sweet cherry contains important

amounts of carotenoids. Although carotenoids are another important bioactive constituent in fruits (Valero and Serrano, 2010), almost no evidence exists on their occurrence in sweet cherry. Valero *et al.* (2011) quantified carotenoids in two sweet cherry cultivars ('Prime Giant' and 'Cristalina'), and found different concentrations in both cultivars, with 'Prime Giant' having significantly higher total carotenoids (1.1 mg per 100 g FW) than 'Cristalina' (0.6 mg per 100 g FW). Leong and Oey (2012) reported individual contents in sweet cherry with concentration of 2.0 mg per 100 g DW for β -carotene, β -cryptoxanthin and α -carotene, and 1.0 mg per 100 g DW for lycopene and lutein.

In sweet cherry, differences in vitamin C concentration at time of harvest have been reported. Thus, cultivar '4-70' had 28.2 mg per 100 g FW (Serrano *et al.*, 2005), while 'Souvenir', 'Samba' and 'Prime Giant' showed ascorbic acid values of 3.98, 2.30 and 5.95 mg per 100 g FW, respectively (Schmitz-Eiberger and Blanke, 2012). In sour cherry, according to Wojdyło *et al.* (2014), the content of ascorbic acid within 33 sour cherry cultivars differed greatly, ranging from 5.5 mg per 100 g FW ('Kelleris 14') to 22.1 mg per 100 g FW ('Morina'), although its content in most of the analysed cultivars was lower than 10.0 mg per 100 g FW.

17.5.2 Temperature and light intensity

Light intensity increases the levels of ascorbic acid, and different growing temperatures (day/night) also affect the TPC. High-temperature growth conditions (25/30°C) significantly enhance the anthocyanin and TPC (Wang, 2006). Recently, there has been increasing interest in growing cherries under plastic greenhouses, especially in cold areas. This cultivation system can influence canopy and soil temperature, and the quantity and quality of transmitted, reflected or absorbed light (Ferretti *et al.*, 2010). The highest levels of nutrients and bioactive components were found in the year characterized by the highest temperature and greatest solar radiation exposure (McCune *et al.*, 2011).

17.5.3 Ripening stage

Fruit ripening is a highly coordinated, genetically programmed process occurring at the later stages of fruit development and involving a series of physiological, biochemical and sensory changes leading to an edible ripe fruit with desirable quality parameters (Valero and Serrano, 2010).

In sweet cherry, the ripening process is characterized by colour changes, from green to red, which can be followed by the evolution of L^* , a^* and b^* parameters, and are due to the accumulation and profile of anthocyanins. In fact, red colour development in sweet cherry is used as indicator of quality and ripening of fresh cherry (Esti *et al.*, 2002; Serrano *et al.*, 2005; Mozetič *et al.*, 2006). Harvesting is usually performed based on the attainment of acceptable fruit size, fruit firmness, colour and concentration of soluble solids. However, there is little available information about the changes in the content of health-promoting compounds during sweet cherry development and ripening on the tree. Serrano *et al.* (2005) reported changes in the concentrations and activities of antioxidants of sweet cherry at 14 different stages of ripeness, with total anthocyanins increasing exponentially from stage 8 to the maximum value at stage 14 (63.3 mg cyanidin equivalent activity per 100 g FW). TAA decreased from stage 1 to stage 8, and increased again from stage 8 to stage 14, coinciding with the TPC and the accumulation of anthocyanins. TAA reached its maximum activity at stage 14, with average ascorbic acid equivalent activity of 50.0 mg per 100 g FW. Thus, harvesting sweet cherries at stage 12 of ripening when the fruit reaches maximum size would support the development of the highest organoleptic, nutritional and functional quality attributes.

Gonçalves *et al.* (2004) investigated total phenolics in four cherry cultivars at two ripening stages and found the lowest total phenolics in cultivar 'Van' at the partially ripe stage (69.0 mg per 100 g FW), compared with the highest in cultivar 'Saco' at the fully ripened stage (264.0 mg per 100 g FW). Similarly, as maturity progressed

in Turkish sweet cherry (unknown cultivar), the total phenolics also increased (Mahmood *et al.*, 2013). In red-coloured fruits, total phenols generally increase during the ripening stage due to the maximal accumulation of anthocyanins and flavonols.

17.5.4 Preharvest treatments

Signalling molecules, such as salicylic acid (SA) and methyl jasmonate, are endogenous plant growth substances that may play a key role in plant growth and development, and in responses to environmental stresses. The effects of SA or acetylsalicylic acid (ASA) treatments (at 0.5, 1.0 and 2.0 mM concentrations) during on-tree cherry growth and ripening were studied in 'Sweetheart' and 'Sweet Late' cultivars, and showed that treated cherries had higher concentrations of total phenolics and total anthocyanins, as well as higher antioxidant activity, in both the hydrophilic and lipophilic fractions (Giménez *et al.*, 2014). On average, treated fruit had 10–15% more phenolics, 15–20% more anthocyanins and 40–60% more antioxidant activity. The authors postulated that preharvest treatments with SA or ASA could be promising tools to improve sweet cherry quality and the health-beneficial effects for consumers.

In sour cherry ('Cigany'), trees were sprayed with 250.0 mg l⁻¹ ethephon 1 week before the anticipated commercial harvest. Fruit from ethephon-sprayed trees had significantly lower soluble solids concentration (SSC), anthocyanin content, antioxidant activity and firmness than those from non-sprayed controls. The ethephon spray did not affect TPC, although its content tended to be higher in fruit from non-treated controls. TA, pH and SSC/TA ratio were not affected by the ethephon spray (Khorshidi and Davarynejad, 2010).

Abscisic acid (ABA) is a plant growth regulator, and plays a variety of important roles throughout the life cycle of a plant. These roles include seed development and dormancy, the plant response to environmental stresses and fruit ripening. ABA concentration is very low in unripe fruit,

but increases as the fruit ripens, so it is believed that ABA plays an important role in regulating the rate of fruit ripening. ABA application 36 days after full blossom increased the total sugar content of fruit and stimulated the accumulation of anthocyanin in sweet cherry. In contrast, ABA and ethephon applications decreased the malic acid content, whereas applications 30 days after full blossom failed to reduce the malic acid levels (Kondo and Inoue, 1977). These results suggest that ABA may be closely related to the maturation of cherry fruit, and that the effects of ABA and ethephon on maturation may vary with the time of application. It was found that ABA content increased rapidly at the straw-coloured stage and reached its highest level 4 days before commercial harvest time. During the straw-coloured stage, the application of exogenous ABA induced its accumulation, anthocyanin biosynthesis and an increase in the maturity index (TSS/TA), thereby promoting fruit ripening (Luo *et al.*, 2014).

Oxalic acid (OA), as a final metabolic product in plants, has many physiological functions, the main one being related to the induction of systemic resistance against diseases caused by fungi, bacteria and viruses by increasing defence-related enzyme activities and secondary metabolites such as phenolics. Trees of 'Sweetheart' and 'Sweet Late' sweet cherry cultivars treated with OA at 0.5, 1.0 and 2.0 mM increased fruit size at harvest, manifested by higher fruit volume and weight. Other quality parameters, such as colour and firmness, were also increased by OA treatments, which were accompanied by increases in total anthocyanins, total phenolics and antioxidant activity (Martínez-Esplá *et al.*, 2014). At the time of harvest, treated cherries had 15–20% more phenolics and 25–30% more anthocyanins, while increases of 70–80% were obtained for TAA.

17.6 Postharvest Factors Affecting Quality and Nutritional Compounds

The sweet cherry horticultural production chain involves a number of steps: production,

harvesting, precooling, cooling, selection, grading, packaging, transport, distribution and consumption. Extension of the postharvest life of sweet cherry depends on three factors: (i) a reduction in dehydration and weight loss; (ii) slowing down the physiological processes of maturation and senescence; and (iii) avoiding the onset and rate of microbial growth. To control these three factors, the main tools are refrigeration and controlling the relative humidity. The optimum temperature for harvest and handling of cherries is between 10 and 20°C (outside this temperature range, more pitting is observed), while the optimum storage temperature is 0°C, with a relative humidity of 90–95% (Romano *et al.*, 2006). Thus, storage at low temperatures is the main postharvest treatment to reduce sweet cherry metabolism, maintain quality and prolong the storability in those perishable fruit and vegetables considered to be non-chilling sensitive, such as sweet cherry fruit. Some evidence exists on the changes in bioactive compounds and antioxidant activity during cold storage, although no general trends have been found. Thus, loss of health-beneficial compounds (phenolics and ascorbic acid) has been found in table grapes, broccoli, pomegranate and apple (Serrano *et al.*, 2011), in which the loss of phenolics was highly dependent on cultivar. However, increases in phytochemicals were reported for sweet cherry during cold storage, although different behaviour has been reported depending on storage temperature. Gonçalves *et al.* (2004) studied the phenolic compounds hydroxycinnamates, anthocyanins, flavonols and flavan-3-ols of 'Burlat', 'Saco', 'Summit' and 'Van' sweet cherry cultivars harvested at two different ripening stages and stored under different cold conditions. Phenolic acid content generally decreased with storage at 1–2°C and increased with storage at 15 ± 5°C. Anthocyanin levels increased at both storage temperatures, while flavonol and flavan-3-ol contents remained quite constant.

The maturity stage at harvest also determines the antioxidant potential after cold storage of sweet cherries. In a study on 11 cherry cultivars harvested at three ripening

stages (S1, S2 and S3), significant increases in anthocyanin content were found during cold storage and subsequent shelf life at 20°C, the accumulation of anthocyanins during storage being attributed to normal sweet cherry ripening (Serrano *et al.*, 2009). HPLC-DAD chromatograms revealed that in all cultivars the main anthocyanins were cyaniding 3-*O*-rutinoside, followed by cyaniding 3-*O*-glucoside and pelargonidin 3-*O*-rutinoside, which increased with ripening from S1 to S3. With respect to total phenolics, an increase in total phenolic compounds as maturity advanced was observed (from S1 to S3) for all cultivars. As mentioned above, neochlorogenic acid was the predominant hydroxycinnamic acid followed by *p*-coumaroylquinic acid, and both increased significantly from S1 to S3 and during storage.

In recent years, particular attention has been paid to the use of natural safe compounds as postharvest treatments to improve the content of bioactive compounds during storage of sweet cherries. Thus, 'Cristalina' and 'Prime Giant' cherries harvested at the commercial ripening stage and treated with SA, ASA or OA at 1 mM before storage under cold temperature showed beneficial effects on maintenance of organoleptic quality by a delay of the postharvest ripening process, manifested by lower acidity, colour changes and firmness losses. This delay was also manifested by a delay in the accumulation of total phenolics, anthocyanins and antioxidant activity (Valero *et al.*, 2011).

Another postharvest treatment with beneficial effects on reducing postharvest ripening of sweet cherry has been the use of edible coatings. In this sense, 'Sweetheart' cherry coated with sodium alginate at several concentrations (1, 3 or 5%, w/v) delayed the evolution of parameters related to postharvest ripening, such as colour, softening and loss of acidity, and reduced respiration rate. In addition, the edible coatings showed a positive effect on maintaining higher concentration of total phenolics and TAA, which decreased in control fruit associated with the over-ripening and senescence processes (Díaz-Mula *et al.*, 2012). Since the

ingestion of fruit and vegetables with higher amounts of phenolics has antioxidant activity 'in vivo' by increasing the plasma antioxidants (Fernández-Panchón *et al.*, 2008), the use of alginate as an edible coating led to fruits with higher proportion of functional properties than control ones. However, no data exist on the bioavailability and bioconversion of phenolic compounds after the intake of sweet cherry fruit, and thus more research is needed on this issue.

17.7 Medicinal, Traditional (Folk) and Other Usage

As described earlier, sweet cherry fruit contains fibre, vitamin C, carotenoids and anthocyanins, each of which may help play a role in cancer prevention. Medicine can be prepared from the stalks of sweet cherry drupes, which are astringent, antitussive and diuretic (Baytop, 1984). The hard, reddish-brown wood (cherry wood) is valued as a hardwood for woodturning, and for making cabinets and musical instruments (Baytop, 1984). In Turkey, sarma, a famous dish traditionally prepared from grape leaves, can also be made out of sweet cherry leaves. Sweet cherry leaves are rolled around a filling usually based on ground meat. It is found in the cuisines of the

former Ottoman Empire from the Middle East to the Balkans and central Europe.

The fruit and stem of the sour cherry are also used to produce medicine and food. Sour cherry is used for osteoarthritis, muscle pain, gout, to increase urine production, and to help digestion (McCune *et al.*, 2011). Sour cherries are eaten as a food or flavouring. Sour cherry fruit contains ingredients that reduce inflammation, protect from oxidative stress in neuronal cells (Wang *et al.*, 1999) and enhance muscle recovery (Connolly *et al.*, 2006). They also contain MLT, which helps to regulate sleep patterns (Pigeon *et al.*, 2010). With regard to sour cherry anthocyanins, *in vitro* studies have demonstrated that they are able to reduce the proliferation of human colon cancer cells in culture (Kang *et al.*, 2003).

17.8 Conclusions

Sweet and sour cherries are popular temperate fruits due mainly to their excellent organoleptic characteristics, especially sweet cherries. In addition, they are important sources of nutrient and bioactive food components, mainly sour cherries, and are potentially beneficial to health, and for this reason should be included as an essential part of the human diet.

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