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Polyphenolic compounds in sour cherry (*Prunus cerasus* L.): composition, health effects, and impact of food processing

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Abstract

Sour cherry (*Prunus cerasus* L.) is a rich source of polyphenolic compounds, which contribute to its numerous health-promoting properties. Fruit contains a variety of bioactive constituents, including anthocyanins, flavonols, and chlorogenic acids, which are associated with antioxidant, anti-inflammatory, and cardioprotective effects. Analyses of these compounds demonstrate the potential of sour cherry to support human health and reduce the risk of chronic diseases. However, the protection of these bioactive compounds is crucial, as food processing methods such as heat treatment, freezing, drying and storage can significantly affect their concentration and biological activity. Sour cherries are commonly processed into products such as juice, concentrates and jams. Jam quality is influenced by its recipe, processing methods, and storage conditions. During jam production, significant losses of polyphenols are observed, particularly anthocyanins, which can decrease by up to 90%. Storage further reduces their levels, with the extent of loss depending on time and temperature. These findings highlight the importance of processing and storage technologies for protecting the bioactive compounds in sour cherry jams.

Keywords Sour cherry, Polyphenols, Anti-inflammatory effects, Antioxidants, Food processing

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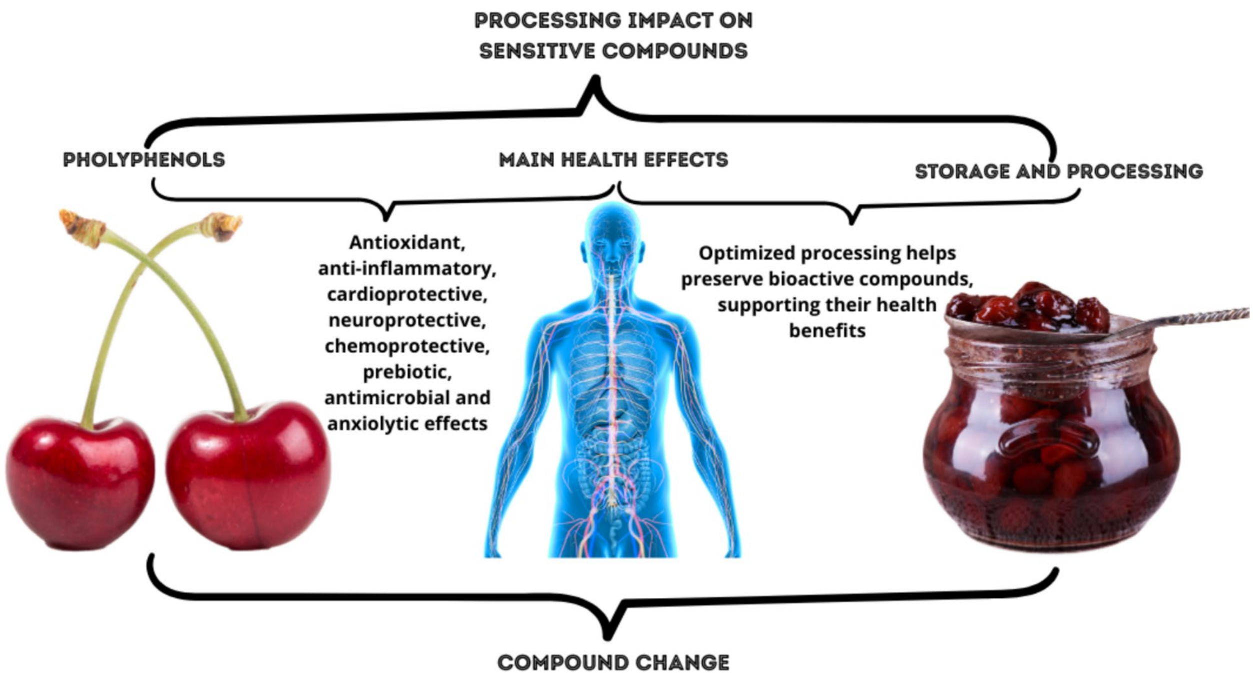
Graphical Abstract



Introduction

Fruits and vegetables are key components of a healthy lifestyle, as their high contents of vitamins and other bioactive compounds can contribute to the prevention of oxidative stress, inflammation, and certain chronic diseases, such as cardiovascular disorders and cancer, when consumed regularly. In addition, these foods are rich sources of dietary fiber and minerals (Kocabas & Sanlier, 2024; Loizzo & Tundis, 2019; Narra et al., 2024).

Sour cherry (*Prunus cerasus* L.*)* is a stone fruit that belongs to the *Rosaceae* family. It is widely cultivated across the world, with most varieties being native to Europe and Asia, where it plays a significant nutritional and economic role (Kimble et al., 2021; Sabou et al., 2021). In recent years, the largest sour cherry producing countries have included Turkey, Russia, Poland, Serbia, and Ukraine, which together account for a major share of global production. For instance, Turkey alone produced approximately 700–900 thousand tons annually in the past decade, consistently ranking as the world's leading producer, followed by Russia and Poland with 150–200 thousand tons per year each. These production values are based on the most recent global agricultural statistics (FAOSTAT, 2023). Its chemical composition largely depends on its variety; additionally, the ripeness stage, cultivation practices, and environmental factors also influence its chemical composition (Serradilla et al., 2016). Sour cherry is a relatively low-calorie fruit, providing approximately 50 kcal per 100 g of fresh fruit, and contains 82–86% water. Its main vitamins are vitamin C, typically 8–15 mg/100 g, and beta-carotene (provitamin A), present at approximately 40–100 µg/100 g. Among minerals, potassium is found in the highest concentration, generally ranging between 170–200 mg/100 g, contributing to the fruit's beneficial effects on electrolyte balance (Blando & Oomah, 2019; Serradilla et al., 2016). The most important bioactive compounds in sour cherries are polyphenols, which are secondary metabolites of plants and have been proven to have a positive effect on health (Mustafa et al., 2020; Bobrysheva et al., 2023). To date, more than 8,000 polyphenolic compounds that perform numerous biological and environmental functions have been identified. These functions include cell-division regulation, hormonal balance, photosynthetic pigment synthesis, nutrient mobilization, ROS scavenging, insecticidal and antimicrobial activity, and allelopathic interactions within plant systems. (Bobrysheva et al., 2023; Sharma et al., 2019). Among other roles, they contribute to the defense mechanisms of plants, exhibiting antimicrobial and insecticidal effects. They also influence cell division, cell differentiation, cell wall strengthening and lignin synthesis. The taste, aroma, and color of fruits are largely attributed to the presence of polyphenolic compounds, which additionally play a role in inhibiting harmful oxidative processes (Nagy, 2016). The polyphenolic composition and, consequently, the nutritional and sensory quality of sour cherry significantly change during ripening. As ripening progresses, the chlorophyll content decreases, whereas the concentration of antioxidant pigments such as anthocyanins and carotenoids increases. Anthocyanins are the most abundant polyphenolic compounds in sour cherry and accumulate primarily in the skin, which substantially contributes to the sensory properties and biological value of the fruit (Blando & Oomah, 2019; Mattioli et al., 2020a, b).

The biological activity of polyphenolic compounds strongly depends on their structure, concentration, and the food processing methods applied. Heat treatment, freezing, drying, and other processing techniques can reduce the amounts of bioactive compounds present in the fruit, which may affect the health benefits of foods. This is particularly important because polyphenols contribute to reducing inflammation, mitigating oxidative stress, and preventing cardiovascular diseases. Therefore, a decrease in their concentration can lead to a reduction in the functional value of foods (Narra et al., 2024). Therefore, summarizing the major classes of polyphenolic compounds in sour cherry and highlighting how processing methods influence their concentration and biological activity are essential.

Major polyphenolic compounds in sour cherry

Among the bioactive compounds in sour cherry, polyphenolic compounds are present in the greatest amounts. These polyphenols can be classified into two main groups: flavonoids and non-flavonoid polyphenols (Fig. 1). Table 1 presents the polyphenolic compounds found in sour cherry and their quantitative ranges on the basis of literature data.

The total polyphenol content of sour cherry varies significantly in the literature because of genetic, cultivation, and environmental factors. A study conducted in 2004 at the New York State Agricultural Experiment Station in Geneva, New York, USA, compared four sour cherry cultivars whose total polyphenol content ranged from 162 to 312 mg gallic acid equivalents (GAE)/100 g fresh weight (FW) (Kim et al., 2005); in contrast, a study conducted in 2011 in Denmark examined 34 sour cherry cultivars

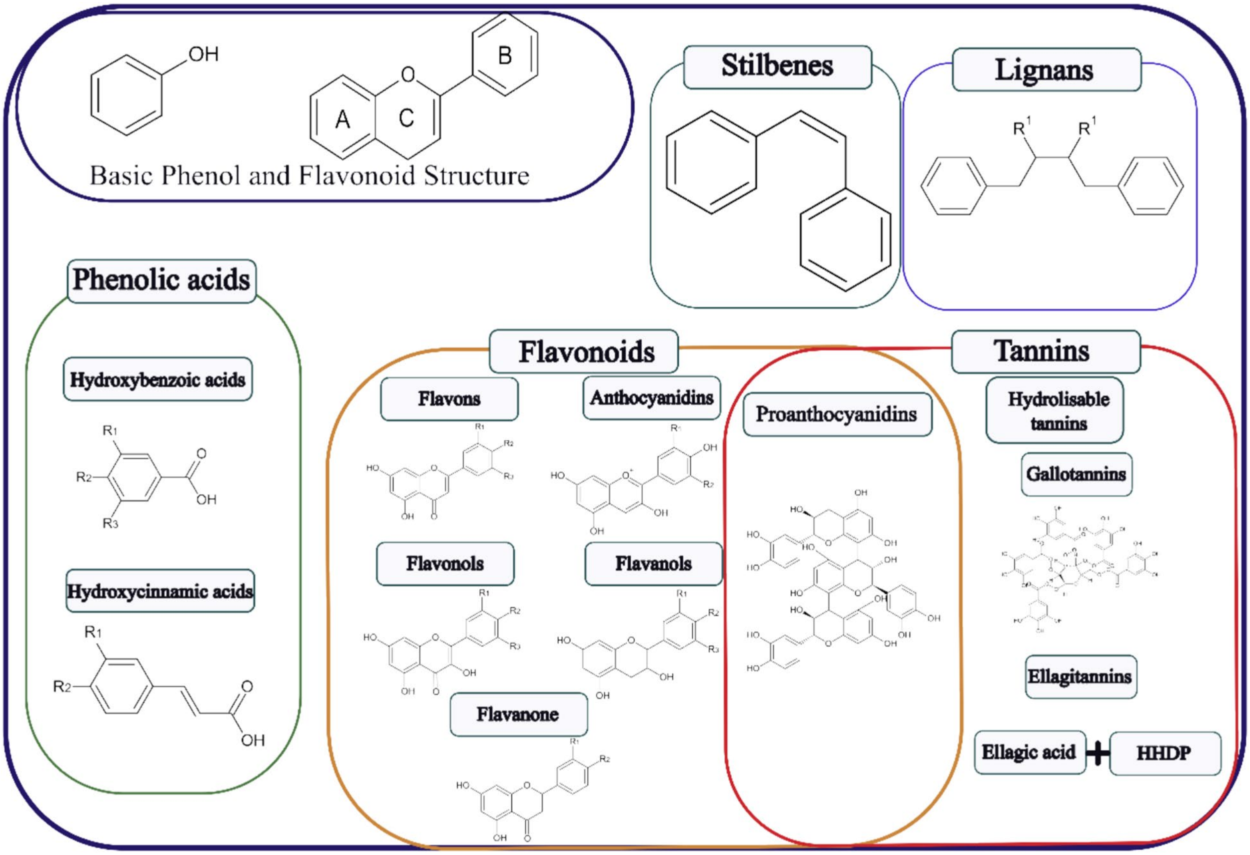


Fig. 1 Classification of polyphenolic compounds. Own editing based on (Prabhu et al., 2021; W. Li et al., 2023; Ciupei et al., 2024; Lang et al., 2024)

Table 1 The main polyphenol compounds in sour cherry fruit. Abbrevation: FW – fresh weight; CE – catechin equivalent; C3GE – cyanidin-3-glucoside equivalent

Compound group	Subgroups chemical formula	Range	Reference
Total polyphenols		74–1276 mg/100 g FW	(Kim et al., 2005) (Viljevac Vuletić et al., 2017) (Khoo et al., 2011) (Sokół-Łętowska et al., 2020)
Flavonoids	**Total flavonoid content**	33.8—114.1 mg CE/100 g FW	(Głowacka et al., 2020)
	Anthocyanins	17.97–493 mg C3G/100 g FW	(Kim et al., 2005) (Viljevac Vuletić et al., 2017) (Khoo et al., 2012) (Proietti et al., 2019) (Głowacka et al., 2020) (Blando et al., 2004) (Sokół-Łętowska et al., 2020):
	Cyanidin-3-O-glucoside (kuromanin) $C_{21}H_{20}O_{11}$	0.52–6.70 mg/100 g FW	(Blando et al., 2004) (Proietti et al., 2019) (Nemes et al., 2018) (Głowacka et al., 2020) (Karaaslan & Yaman, 2016) (Kim et al., 2005)
	Cyanidin-3-O-rutinoside (keracyanin) $C_{27}H_{30}O_{15}$	1.6–183 mg/100 g FW	(Nemes et al., 2018) (Proietti et al., 2019) (Głowacka et al., 2020) (Blando et al., 2004) (Kim et al., 2005)
	Cyanidin-3-O-glucosylrutinoside $C_{33}H_{41}O_{20}$	2–270 mg/100 g FW	(Blando et al., 2004) (Nemes et al., 2018) (Proietti et al., 2019) (Kim et al., 2005)
	Cyanidin-3-O-sophoroside $C_{27}H_{30}O_{16}$	0.71–39.2 mg/100 g FW	(Proietti et al., 2019) (Blando et al., 2004)
	Peonidin-3-O-rutinoside $C_{28}H_{32}O_{15}$	1.76–76.7 mg/100 g FW	(Proietti et al., 2019) (Kim et al., 2005)
	Flavonols	1.7–25 mg/100 g FW	(Głowacka et al., 2020) (Sokół-Łętowska et al., 2020):
	Quercetin	0.06- 8.20 mg/100 g FW	(Kim et al., 2021) (Lugasi & Takács, 2002) (Nemes et al., 2018)
	Quercetin-3-O-rutinoside (Rutin or Sophorin) $C_{27}H_{30}O_{16}$	0.04–5.7 mg/100 g FW	(Głowacka et al., 2020) (Nemes et al., 2018) (Kim et al., 2005)
	Quercetin-3-O-glucoside (Isoquercetin) $C_{21}H_{20}O_{12}$	0.1–0.7 mg/100 g FW	(Głowacka et al., 2020) (Kim et al., 2005)
	Kaempferol		
	Kaempferol-3-O-glucoside (Astragalin) $C_{21}H_{20}O_{11}$	0.1–3.3 mg/100 g FW	(Głowacka et al., 2020)
	Kaempferol-3-O-rutinoside $C_{27}H_{30}O_{15}$	0.30- 1.29 mg/100 g FW	(Kim et al., 2005)

Table 1 (continued)

Compound group	Subgroups chemical formula	Range	Reference
Non-flavonoid polyphenols	**Phenolic acids**	1.7–126.99 mg/100 g FW	(Głowacka et al., 2020) (Sokół-Łętowska et al., 2020)
	Hydroxycinnamic acids:		
	Chlorogenic acid $C_{16}H_{18}O_9$	0.5–6.1 mg/100 g FW	(Głowacka et al., 2020) (Nemes et al., 2018) (Kim et al., 2005)
	Neochlorogenic acid $C_{16}H_{18}O_9$	6.74–59 mg/100 g FW	(Nagy-Gasztonyi et al., 2010) (Kim et al., 2005)

and reported total polyphenol contents ranging between 74 and 754 mg GAE/100 g FW. Most cultivars have total polyphenol contents between 200 and 400 mg GAE/100 g FW (Khoo et al., 2011). In Croatia, over a period of four years, the total polyphenol content of sour cherry cultivars grown at two different locations ranged between 487 and 1276 mg GAE/100 g FW. Generally, the same cultivars presented lower polyphenol contents at one of the sites, indicating that environmental factors have a more significant impact than the genetic characteristics of the cultivars do (Viljevac Vuletić et al., 2017).

Flavonoids

Flavonoids have a fundamental 15-carbon C6–C3–C6 flavone backbone composed of two benzene rings (A and B) connected by a three-carbon pyran ring (C). The antioxidant capacity of flavonoids is influenced by the position of the catechol group on the B ring relative to the C ring, as well as the number and placement of hydroxyl groups on the B-ring catechol (Dias et al., 2021). In a four-year study conducted in Poland examining four sour cherry cultivars from both organic and conventional cultivation, total flavonoid values ranged between 38.6 and 114.1 mg catechin equivalents (CE)/100 g FW. Both the lowest and highest values were observed in samples from organic cultivation (Głowacka et al., 2020); thus, the effect of cultivation method on this parameter is relatively low. Flavonoids play a key role in determining the color, taste, and structural stability of plants. These compounds contribute to plant tolerance to environmental stress and are involved in plant metabolism and photosynthesis, including the regulation of cell division, synthesis of photosynthetic pigments, and antioxidant defense. Chemically, they can be classified into several subgroups. The most abundant flavonoids in sour cherry are anthocyanins, which accumulate mainly in the skin and contribute to sensory properties and antioxidant defense, while other flavonoids, including flavonols, are also present and play a role in stress protection (Nagy, 2016; Sharma et al., 2019).

Anthocyanins are responsible for the characteristic pigmentation of sour cherry. Anthocyanins are the sugar-bound derivatives of anthocyanidins (aglycones). They are built on a flavylium cation core, which can be hydroxylated at various positions—commonly C3, C5, C6, C7, and C3', C4', C5'—resulting in different anthocyanidins. Their color is strongly pH-dependent: at acidic pH they appear red, at near-neutral pH they shift toward purple, and at alkaline pH they became blue. This color variation is influenced by structural factors such as the number of hydroxyl groups and the type and position of sugar and acyl residues attached to the aglycone. The λ-max of anthocyanins typically ranges from 490–540 nm. Anthocyanins are more water-soluble and highly sensitive to environmental factors, highlighting the need for careful consideration during processing and storage (Alappat & Alappat, 2020; Khoo et al., 2017; Mattioli et al., 2020a, b). The total anthocyanin content of sour cherries varies between 17.97 and 493 cyanidin-3-O-glucoside equivalents (C3G)/100 g FW (Blando et al., 2004; Kim et al., 2005; Khoo et al., 2012; Viljevac Vuletić et al., 2017; Proietti et al., 2019; Głowacka et al., 2020; Sokół-Łętowska et al., 2020). More than 700 anthocyanin compounds have been identified, but 90% of them can be traced back to just six anthocyanidins: cyanidin, pelargonidin, delphinidin, peonidin, petunidin, and malvidin, which occur abundantly in nature (Wallace & Giusti, 2019). The most abundant anthocyanin compounds in sour cherry are cyanidin-3-O-rutinoside and cyanidin-3-O-glucosylrutinoside. Additionally, relatively small to moderate amounts of cyanidin-3-O-glucoside, peonidin-3-O-rutinoside, and cyanidin-3-O-sophoroside are present. The quantity of cyanidin-3-O-rutinoside in sour cherry varies widely, ranging from 1.6 to 183 mg/100 g, similar to cyanidin-3-O-glucosylrutinoside, for which the literature reports values between 2 and 270 mg/100 g FW. In an Italian study examining three sour cherry cultivars, the content of cyanidin-3-O-rutinoside was observed within a relatively narrow range (9.26–25.26 mg/100 g) (Blando et al., 2004). In a comparative study of organic and conventional sour cherries in Poland, the cyanidin-3-O-rutinoside content ranged between 26.3 and 103.1 mg/100 g FW. The highest value (103.1 mg/100 g) was measured in an organic cultivar (*Keleris 6*), whereas the lowest value (26.3 mg/100 g) was found in a conventionally grown cultivar (*Pándy 103*) (Głowacka et al., 2020). In Hungary, during the analysis of the *Újfehértói fürtös* cultivar, among the three identified cyanidin compounds, cyanidin-3-O-rutinoside was present in the highest amount (183 mg/100 g FW). However, in the same sample, the cyanidin-3-O-glucosylrutinoside content was much lower, measuring only 2 mg/100 g FW (Nemes et al., 2018). In contrast, in an Italian study analyzing three sour cherry cultivars, among the four detected cyanidin compounds, cyanidin-3-O-glucosylrutinoside was present in the highest proportion, ranging from 17.3 to 51.89 mg/100 g (Blando et al., 2004). In another study conducted in Italy, cyanidin-3-O-glucosylrutinoside accounted for 67% of the total anthocyanin compounds, with contents ranging from 39.5 to 270.8 mg/100 g FW, suggesting that the phenolic composition can vary significantly depending on the cultivation site (Proietti et al., 2019).

The amount of cyanidin-3-O-glucoside in sour cherry is generally relatively low, ranging from 0.52 to 6.70 mg/100 g FW. However, in the analysis of the Hungarian *Újfehértói fürtös* cultivar, cyanidin-3-O-glucoside was among the main anthocyanins, with a content of 4.29 mg/100 g FW (Nemes et al., 2018). In a 2020 Polish study, which conducted a detailed analysis of four organic and four conventionally grown sour cherry cultivars (*"Oblacinska", Keleris 16, Pándy 103, Debreceni bőtermő*), significant variation in cyanidin-3-O-glucoside content was observed among the cultivars. The values ranged between 3.26 and 6.70 mg/100 g FW (Głowacka et al., 2020). Lower values were reported elsewhere, where concentrations varied between 0.88 and 1.31 mg/100 g FW, likely due to factors such as cultivar, ripening stage, and biochemical changes during maturation (Karaaslan & Yaman, 2016; Mitić et al., 2012). The concentration of cyanidin-3-O-sophoroside ranges from 0.71 to 39.2 mg/100 g FW (Blando et al., 2004; Proietti et al., 2019). The detected amount of peonidin-3-O-rutinoside in sour cherry was also relatively low, with a value of 1.76 mg/100 g according to a South Korean study. (Kim et al., 2005), however, in an Italian study, much higher values were detected, ranging from 15 to 76.7 mg/100 g (Proietti et al., 2019).

Flavonols, which are flavonoids, contain a ketone group. There is a double bond between C2 and C3 and a carbonyl group at C4. These compounds have a yellowish color, resulting in strong absorption at 340–380 nm. The amount of flavonols in sour cherry is estimated to be between 1.7 and 25 mg/100 g FW (Głowacka et al., 2020). Quercetin and kaempferol are the most significant flavonols found in sour cherry (Sokół-Łętowska et al., 2020).

In sour cherry, quercetin and kaempferol occur mainly in glycosylated forms. The quercetin content in sour cherry ranges from approximately 0.06 to 8.20 mg/100 g FW (Lugasi & Takács, 2002; Nemes et al., 2018; Kim et al., 2021). The most significant quercetin derivatives are quercetin-3-O-rutinoside (rutin) and quercetin-3-O-glucoside. The rutin content in sour cherry is greater than that of quercetin-3-O-glucoside, ranging from approximately 0.04 to 5.7 mg/100 g FW (Kim et al., 2005; Nemes et al., 2018; Głowacka et al., 2020). The content of quercetin-3-O-glucoside ranges between 0.1 and 0.7 mg/100 g FW (Kim et al., 2005; Głowacka et al., 2020).

Kaempferol is a flavonol compound with hydrophobic properties. The total kaempferol content in sour cherries ranges between approximately 0.30 and 1.29 mg/100 g FW. The most significant kaempferol derivatives are kaempferol-3-O-glucoside and kaempferol-3-O-rutinoside. The kaempferol-3-O-glucoside content varies between 0.1 and 3.3 mg/100 g FW in sour cherries, whereas kaempferol-3-O-rutinoside is present in smaller amounts, approximately 0.30 to 1.29 mg/100 g FW (Głowacka et al., 2020).

Non-flavonoid polyphenols

Among polyphenols, phenolic acids can be considered as the simplest compounds and are the best-known non-flavonoid phenolic compounds. These compounds are characterized by a distinctive aromatic smell. They are carboxylic acids derived from either a benzoic acid or cinnamic acid backbone. The phenolic acids belonging to the cinnamic acid group found in sour cherry include chlorogenic acid and neochlorogenic acid (Blando & Oomah, 2019; Sokół-Łętowska et al., 2020).

Chlorogenic acid is one of the major phenolic acids in sour cherry, and it is concentration shows a broad variation depending on cultivar and growing conditions. In a detailed study comparing organic and conventional sour cherries, chlorogenic acid levels varied between 1.0 and 6.1 mg/100 g FW. The highest amount was measured in an organically grown cultivar; however, high values were also observed among conventionally grown cherries (up to 5.8 mg/100 g FW). The organic sour cherry cultivars contained significantly more chlorogenic acid in three out of the four years examined (Głowacka et al., 2020). In the Hungarian study of the Újfehértói fürtös cultivar, the chlorogenic acid content was 0.51 mg/100 g FW, which falls within the lower range of chlorogenic acid levels found in sour cherry (Nemes et al., 2018). A similar range of values was reported in South Korea; however, one cultivar showed a high concentration, whereas the other three cultivars examined contained less than one quarter of that amount (Kim et al., 2005).

The amount of neochlorogenic acid is higher than that of chlorogenic acid. The total neochlorogenic acid content ranges from 6.74 to 59 mg/100 g FW, with significant variations observed between both growing locations and cultivars (Kim et al., 2005; Nagy-Gasztonyi et al., 2010).

Biological effects of the main polyphenolic compounds found in sour cherry on the basis of animal and human studies

Although sour cherries contain significant amounts of these bioactive compounds, relatively few studies have examined their biological effects specifically using extracts isolated from sour cherry fruit. Therefore, in this section, we also summarize findings from studies where the same compounds were isolated from other dietary sources, to provide a broader understanding of their potential health effects and to highlight this existing research gap.

FLAVONOIDS

Anthocyanins

Cyanidin-3-O-glucoside A diet rich in berries and some red stone fruits like sour cherry can significantly contribute to the prevention of various diseases, in part because of their high content of cyanidin-3-O-glucoside (C3G), which is well absorbed and highly bioavailable. In a 16-week study conducted in an Alzheimer's disease mouse model, prolonged C3G treatment was shown to reduce the formation of amyloid-β plaques-aggregates that accumulate in the brain during Alzheimer's disease. Additionally, it decreases pathological modifications of the tau protein, which is located in the brain's neurons. The treatment also promoted autophagy and enhanced neuronal communication while regulating the PI3K/Akt/GSK3β signaling pathway. These findings suggest that C3G may protect neurons and improve cognitive function, highlighting its potential as a promising therapeutic agent for the treatment of Alzheimer's disease (Baek et al., 2023). Moreover, C3G treatment has been shown to enhance glucose metabolism, which may contribute to its beneficial effects in nonalcoholic fatty liver disease (NAFLD). The administration of this compound reduced oxidative damage in the liver, suppressed NLRP3 inflammasome activation, and decreased lipid accumulation in hepatocytes. 16 weeks of C3G supplementation may improve liver conditions, particularly through its beneficial effect on restoring glucose metabolism (Li et al., 2020). The effects of anthocyanin compounds found in blackberries on the gut microbiota were investigated, and the antioxidant activity of their metabolites was analyzed. After 6 h of fermentation, C3G was completely degraded, and the resulting metabolic products improved glucose metabolism and reduced oxidative damage in HepG2 cells (Gowd et al., 2019). The role of C3G in regulating the NF-κB signaling pathway has also been investigated, with a particular focus on intestinal inflammatory processes. In vitro studies demonstrated that this compound can attenuate inflammation induced by TNF-α in both intestinal epithelial and endothelial cells, thereby potentially aiding in the treatment of inflammatory bowel diseases and providing protection for the gut microbiota (Ferrari et al., 2017). The antioxidant, antidiabetic, anti-inflammatory, and cytoprotective effects of C3G have been investigated through various mechanisms, with particular attention to disorders induced by oxidative stress. In vitro studies demonstrated that C3G reduced the levels of reactive oxygen species (ROS). In vivo models revealed that cytoprotective effects are mediated via the Nrf2/ARE signaling pathway. Although the antioxidant potential of C3G through the modulation of the Nrf2 pathway has been less extensively studied, these findings suggest that C3G has multiple health-promoting properties, including anti-inflammatory effects and protection against DNA damage (Rahman et al., 2021). An in vivo animal study demonstrated that C3G and its phenolic acid metabolites mitigate light-induced degeneration through activation of the Nrf2/HO-1 (nuclear factor erythroid 2-related factor 2/heme oxygenase-1) pathway. Pigmented rabbits received supplementation with C3G, protocatechuic acid (PCA), and ferulic acid (FA) at a dosage of 0.11 mmol/kg/day for a total of 3 weeks. These results suggest that C3G and its metabolites provide protection against light-induced damage, likely due to their potent antioxidant and anti-inflammatory properties (Wang et al., 2016). The role of C3G in preventing cadmium (Cd)-induced toxicity to the female reproductive system has been investigated. Oral administration of C3G significantly reduced the impact of cadmium on the thickness of the uterine epithelial layer. Additionally, C3G demonstrated antiestrogenic effects by attenuating cadmium-induced endometrial cell proliferation and increasing progesterone receptor expression, highlighting the potential of C3G supplementation as a dietary intervention for the prevention of female reproductive toxicity caused by cadmium exposure (Yang et al., 2022a, b). In a mouse model study, C3G and protocatechuic acid (PCA, a phenolic metabolite) were shown to provide protective effects against heat shock-induced damage to the testes. These two compounds increase the tolerance of the testes to heat stress by mitigating the cellular stress response, thereby supporting the maintenance of normal testicular function. Furthermore, the treatment improved the antioxidant mechanisms in the testes and helped alleviate disruptions in spermatogenesis (Cai et al., 2023).

These studies reinforce that C3G plays a crucial role in maintaining a healthy gut microbiota and regulating inflammatory processes, while also exerting antioxidant and cytoprotective effects.

Cyanidin-3-O-rutinoside In vitro and in vivo studies the effects of cyanidin-3-O-rutinoside (C3R) were examined on intestinal α-glucosidase. C3R delayed carbohydrate absorption by inhibiting α-glucosidase, indicating that it is effective in regulating carbohydrate metabolism, which may help in the prevention and treatment of diabetes mellitus (Adisakwattana et al., 2011). Rat INS-1 cells were used in a study that demonstrated that C3R may help reduce hyperglycemia in diabetic patients. At concentrations of 60, 100, and 300 μM, C3R significantly increased insulin secretion through intracellular Ca^{2+} signaling. Exposure of the cells to 100 μM C3R had no effect on their viability, indicating that C3R can be safely used and may aid in improving high blood sugar levels in diabetic patients (Kongthitilerd et al., 2022). When the lipid-lowering effect of C3R was investigated in vitro, C3R reduced cholesterol uptake in Caco-2 cells, prevented micelle formation, and bound to bile acids, which contributed to the reduction in cholesterol absorption. This revealed that C3R inhibits lipid absorption; thus, it may be suitable for lowering lipid levels (Thilavech & Adisakwattana, 2019). The lipid-lowering effect of C3R extracted from Mori Fructus (white mulberry) was studied in high-fat diet (HFD)-induced hyperlipidemic mice. These results showed that this compound significantly reduced serum lipid levels and alleviated liver damage caused by the HFD. Analysis of the gut microbiota confirmed that C3R altered specific gut microbiota compositions but did not affect their diversity (Zhong et al., 2025). Rat models have demonstrated that C3R has a positive effect on the vascular system and is capable of inhibiting glycation. C3R was administered intravenously (15–25 μmol/kg body weight) to male animals, and it was shown to significantly reduce arterial blood pressure (Thilavech et al., 2017). Lyophilized acai pulp (AP) and C3R effects have also been studied in rat models. These results suggest that acai pulp may have anticancer properties and could aid in the prevention of colon cancer. C3R was shown to reduce the mobility of cancer cells (Fragoso et al., 2018). The effect and mechanism of C3R were studied in leukemia and lymphoma cell lines. C3R was able to induce apoptosis, i.e., programmed cell death, in HL-60 leukemia cells in a dose- and time-dependent manner. Additionally, C3R caused the accumulation of peroxides in the cells, which promoted apoptosis. It activates the p38 MAPK and JNK signaling pathways, which play key roles in the cellular response, and it also activates the Bim protein, which mediates mitochondrial apoptosis. Notably, C3R does not increase ROS levels and has no toxic effects on human blood cells, indicating that it selectively targets leukemia cells (Feng et al., 2007).

An examination of its anti-inflammatory effect revealed that C3G and C3R achieved increased plasma concentrations in a dose-dependent manner (Brunetti et al., 2023).

Cyanidin-3-O-glucosylrutinoside Although there are currently limited scientific data available on cyanidin-3-O-glucosyl-rutinoside (C3GR), some studies have shown promising effects. Experiments conducted on rat models demonstrated that anthocyanins, including C3GR, have health-promoting effects, as C3GR was detected in target tissues (Kirakosyan et al., 2015). The anti-inflammatory effect of C3GR has been demonstrated, as has its potential role in alleviating gout symptoms. In experiments conducted on an acute gout mouse model, clinically relevant doses of tart cherry juice concentrate significantly reduced inflammatory processes (Schlesinger et al., 2022).

Flavonols (Quercetin and Kaempferol)

Quercetin-3-O-rutinoside (rutin) Mice were administered 10 mg/kg body weight quercetin-3-O-rutinoside (rutin), followed by a single exposure of the chest region to radiation for investigating the effects of radiation-induced fibrosis. The results showed that this compound provided protection to the lungs against radiation by regulating the NF-κB/TGF-β1 signaling pathway (Verma et al., 2022). Mouse models were also used to study the ability of the rutin to protect the entire body against gamma radiation. It regulates apoptosis, protecting the gastrointestinal tract from the effects of radiation (Dutta & Dahiya, 2023). The pharmacological effects of rutin, are widely studied, with particular attention given to cancer research, where it is used mainly for its cancer-preventive and therapeutic properties. Chemotherapy drugs can cause serious side effects, so rutin can be considered a safe alternative. In addition to its significant antioxidant effect in healthcare, it is also considered safe and cost-effective (Imani et al., 2021). Combining routine chemotherapy drugs greatly improved the effectiveness of treatment, reducing tumor progression (Liu et al., 2024). Rutin, kaempferol, and kaempferol derivatives were tested in combination against *Escherichia coli* and *Salmonella enteritidis*. The results revealed that the flavonoids in the plant extract exhibited antibacterial and antibiofilm activity (Yarmolinsky et al., 2022).

Diabetic kidney disease (DKD) is a common and serious complication of diabetes, for which there is currently no complete cure. An 8-week animal study revealed that rutin significantly improved kidney function in mice, which may indicate that rutin is worthy of further investigation because of its potential kidney-protective effects and that the exact mechanisms of action need to be explored (Dong et al., 2023). Preclinical studies have demonstrated that rutin has analgesic properties (Forouzanfar et al., 2025). This research highlighted that, although previous findings show promise regarding routine use, further studies are required to confirm their safety and therapeutic efficacy before they can be considered suitable for human application (Forouzanfar et al., 2025).

Quercetin-3-O-glucoside (isoquercitrin) Methanol leaf extract from *Erica multiflora* is highly effective in alleviating the symptoms of metabolic syndrome (MS) and quercetin-3-O-glucoside (Q3G) was found as one of the main active ingredients. In vivo studies showed that oral administration of this compound reduces obesity and cardiovascular disease, has a beneficial effect on the lipid profile, has anti-inflammatory effects, and enhances the activity of antioxidant enzymes (Khlifi et al., 2020). The antitumor potential of Q3G was studied in an animal model of colon cancer, where it was shown that treated mice had approximately 65% fewer blood vessels (reduced angiogenesis) than did the control group. These findings suggest that Q3G may contribute to the inhibition of tumor vascularization, which is one of the possible anticancer mechanisms (da Silva et al., 2022). The effects of compounds found in blueberry leaves have been investigated in animal experiments, which revealed that a nanoemulsion rich in Q3G increased dopamine levels in the brains of mice in addition to promoting antioxidant activity in the liver and mitigating oxidative stress-induced damage in the brain, thus demonstrating an overall beneficial antiaging effect (Yu & Chen, 2023). Q3G may also provide protection against nonalcoholic fatty liver disease, as studies in mouse models have shown that Q3G treatment improved liver function, reduced inflammation, and decreased lipid accumulation (Jin et al., 2024). Q3G has shown remarkable cardioprotective effects both in vivo and in vitro. It was demonstrated to inhibit cardiomyocyte apoptosis by regulating the Phlpp1/AKT/Bcl-2 signaling pathway, thereby reducing changes in mitochondrial membrane permeability and the release of cytochrome C from the mitochondria, which are critical steps in the initiation of apoptotic processes. Overall, these findings suggest that this compound may protect heart muscle cells by decreasing cellular damage (Wang et al., 2024). Q3G is a flavonoid that may help reduce nervous system damage. It has been shown to mitigate intracellular Ca^{2+} overload, thereby contributing to a reduction in neurodegenerative processes. Additionally, it shows promise as a potential treatment for brain injuries (Guo et al., 2024). The effectiveness of Q3G was investigated in nasopharyngeal carcinoma patients, with the aim of identifying possible regulatory mechanisms. These results confirmed that Q3G significantly reduced the viability and proliferation of CNE1 and HNE1 cells in a concentration-dependent manner. This compound also markedly decreased the activity of inflammation-related molecules such as nuclear factor kappa B (NF-κB), AMP-activated protein kinase (AMPK), and interleukin-1β (IL-1β). In vivo experiments have shown that Q3G reduces tumor growth and promotes lipid peroxidation as well as ferroptosis (Luo et al., 2024).

Kaempferol-3-O-glucoside Kaempferol-3-O-glucoside (K3G) has been studied in animal models of age-related cognitive decline and microglial inflammation. Oral administration of K3G to SAMP8 model mice revealed that this compound improved memory and learning functions and stimulated the expression of estrogen receptors. Furthermore, it reduced microglial activity and the expression of inflammatory markers. These results suggest that K3G may be a new therapeutic option for treating age-related cognitive impairments (Liu et al., 2023). The consumption of *Erica multiflora*, whose methanolic leaf extract contains K3G as one of its compounds, mitigated obesity, insulin resistance, and cardiovascular diseases (Khlifi et al., 2020).

Kaempferol 3-O-rutinoside In vitro studies on *Tetrastigma hemsleyanum* containing kaempferol-3-O-rutinoside (K3R) revealed a significant reduction in the viability of lung adenocarcinoma cells compared with that of control cells. Thus, both K3R and THTF (*Tetrastigma hemsleyanum* total flavonoids) present potential therapeutic options for the prevention and treatment of lung cancer (Li et al., 2021a, b). Studies on K3R extracted from the leaves of *Antidesma acidum* Retz demonstrated that its application has a significant effect on glucose uptake. K3R increases glucose uptake in skeletal muscle L6 cells by inducing sirtuin-1 (SIRT1), which in turn stimulates GLUT4 translocation. Overall, this compound improves insulin sensitivity, which is particularly important for the treatment of type 2 diabetes mellitus (T2DM) (Kashyap et al., 2023). K3R, which is isolated from the plant *Tetrastigma hemsleyanum*, has significant antipyretic effects on a mouse fever model. K3R can be effectively isolated from the roots of plants, and at a concentration of 4 μM, it reduces fever in mice more effectively than ibuprofen and acetaminophen do in these models (Zheng et al., 2024).

NON-FLAVONOID POLYPHENOLS

Phenolic acids

Chlorogenic acid Chlorogenic acids (CGAs) are a group of esters formed between hydroxycinnamic acids (such as caffeic, ferulic, and p-coumaric acids) and quinic acid. Neochlorogenic acid (nCGA, or 3-CQA) represents another important isoform. These compounds are also present in sour cherries (H. E. Blando & Oomah, 2019; Khoo et al., 2017).

The chlorogenic acid (CGA) is found having potential anticancer properties, and have significant role in the function of microsomal glucose-6-phosphate translocase (G6PT), since chlorogenic acid is an inhibitor of microsomal G6PT. The combined antitumor effects of G6PT and CGA are capable of regulating the intracellular signaling and invasiveness of glioma cells (Belkaid et al., 2006). The anxiolytic effect of CGA found in fruits has been demonstrated in mouse model. A dose of 20 mg/kg body weight significantly reduced anxiety-related behaviors, suggesting that it may help alleviate symptoms of depression. In addition to its anxiolytic effects, this compound also exhibits antioxidant properties by protecting blood granulocytes from damage caused by free radicals (Bouayed et al., 2007). The neuroprotective effect of CGA has also been confirmed, as it significantly improved cognitive impairment by inhibiting acetylcholinesterase activity and reducing oxidative stress. Therefore, CGAs may support cognitive functions and play a role in the treatment of Alzheimer's disease and other neurodegenerative disorders (Kwon et al., 2010). They compared decaffeinated coffees containing CGA with caffeinated coffees and reported that coffee with CGA improved the mood to a lesser extent (Cropley et al., 2012). It has been shown that 400 mg of CGA (equivalent to two cups of coffee) in the short term reduces blood pressure, which may also indicate a cardioprotective effect (Mubarak et al., 2012). Phenolic compounds protective of the intestines was identified. A total of four phenolic acids were found-CGA, 5-caffeoylquinic acid, protocatechuic acid, and caffeic acid-which may contribute to maintaining the health of the intestinal barrier. The most prominent effect was observed with CGA, as it increased transepithelial electrical resistance (TEER) and reduced paracellular permeability while also stabilizing intestinal barrier function. Thus, these compounds may play important roles in maintaining intestinal homeostasis (Song et al., 2022).

Neochlorogenic acid The anti-inflammatory effect of neochlorogenic acid (nCGA) has been investigated in several studies. Neochlorogenic acid inhibits lipopolysaccharide-induced inflammatory responses and strongly stimulates the gene expression of proteins regulated by Nrf2/ARE, such as NQO-1 and HO-1 (Park et al., 2018). A similar conclusion was reached in a study investigating the anti-inflammatory effect of nCGA extracted from mulberry leaves (*Morus alba* L.) in a cell line. nCGA shows promise as a natural anti-inflammatory agent for the treatment of acute pneumonia (Gao et al., 2020). The effect of nCGA was investigated in an asthmatic mouse model and in human airway epithelial cells (BEAS-2B), with a focus on markers of the inflammatory response and oxidative stress via molecular biology methods. Neochlorogenic acid reduced airway hyperresponsiveness, eosinophil infiltration, and goblet cell hyperplasia in the lungs of asthmatic mice. Additionally, it inhibited the expression of type 2 cytokines, mitigated oxidative stress, decreased monocyte adhesion to BEAS-2B cells, and decreased the production of inflammatory cytokines and reactive oxygen species. Neochlorogenic acid shows promise as a potential immunomodulator for the treatment of asthma and allergic airway diseases (Cheng et al., 2025).

The effects of neochlorogenic acid (3-CQA) on intracellular lipid accumulation and liver inflammation induced by oleic acid were investigated in vitro via cell culture. The actions of 3-CQA were evaluated through the regulation of miR-34a. Treatment with 3-CQA reduced oleic acid-induced lipid accumulation. Additionally, it inhibited the expression of SREBP1, FASN, SREBP2, and HMG-CoA reductase, which are involved in lipid and cholesterol synthesis. The treatment also increased the expression of enzymes regulating fatty acid β-oxidation and suppressed miR-34a levels, leading to the activation of SIRT1 and AMPK. This contributed to the reduction in lipid accumulation and alleviation of liver inflammation (Yu et al., 2021). The effects of nCGA, the main active compound in mulberry leaf extract (MLE), on the proliferation and migration of vascular smooth muscle cells (VSMCs, A7r5 cell line) cultured under diabetic conditions from the rat aorta were investigated. Cell migration was assessed via wound healing and Transwell assays, and signaling mechanisms were explored via molecular biology methods. Both MLE and nCGA significantly reduced VSMC proliferation and migration, which may help prevent atherosclerosis. The treatment decreased the levels of PI3K, FAK, and small GTPase proteins, thereby inhibiting the Ras and FAK signaling pathways, which play key roles in increased cell growth and motility (Yang et al., 2022a, b). The effect of nCGA on mitochondrial calcium overload mediated by the mitochondrial calcium uniporter (MCU) in cancer cells was investigated, with the aim of evaluating the impact of nCGA treatment on cellular calcium homeostasis and its potential anticancer mechanism. Neochlorogenic acid induced significant calcium overload in cancer cells, which may offer a novel therapeutic approach for cancer treatment. This mechanism provides a basis for the future application of MCU-targeted calcium modulation in tumor therapies, opening new possibilities for cancer treatment (Li et al., 2021a, b).

Table 2 summarizes the health effects of compounds that also occur in sour cherry. The table presents the reported biological activities of these compounds based on findings from various plant sources, not exclusively from sour cherry.

Effects of storage and processing on the bioactive compounds in sour cherries and sour cherry products

The concentration of bioactive compounds in sour cherries and their processed products can undergo significant changes throughout storage and processing, which may influence the health benefits of the final product. The processing and storage conditions play crucial roles in determining the extent to which polyphenolic compounds decrease. However, with respect to sour cherries, relatively few studies have attempted to quantify these effects.

Throughout the preparation of sour cherry nectar, samples were taken at every step of processing to evaluate changes in flavonoid and anthocyanin contents. The final product showed an approximately 38% loss of flavonoids, whereas the loss of anthocyanins was greater, reaching nearly 56% (Toydemir et al., 2013). Furthermore, a study examined the anthocyanin content of juices prepared from two Hungarian sour cherry varieties (*Érdi bőtermő* and *Kántorjánosi 3)*, which were treated at 70, 80, and 90 °C for varying durations. The total anthocyanin content decreased with increasing time and temperature in both varieties. Specifically, a 4-h heat treatment at 90 °C resulted in an approximately 38–45% reduction, whereas juices treated for the same duration at a lower temperature (70 °C) showed only a 17–18% loss. In particular, the concentrations of the two major individual anthocyanins, C3GR and C3R, were significantly reduced during heat treatment. For example, in *Érdi bőtermő* juice, C3GR decreased from 348 mg/L to 124 mg/L at 90 °C, while C3R decreased from 177 mg/L to 58.4 mg/L, highlighting how processing specifically affects individual bioactive compounds (Szalóki-Dorkó & Végvári, 2015). When homemade sour cherry juice was subjected to heat treatment, including conventional heating (20 min), microwave treatment (22 min), and boiling (10 min), the greatest decrease in total monomeric anthocyanin content—a 53% reduction—was observed after conventional heating. In contrast, the other two heat treatments resulted in much lower anthocyanin degradation, ranging from 2–4% (Yıldız et al., 2022). Additionally, when two sour cherry varieties (*Oblačinska* and *Marasca*) and their products made according to traditional recipes, including fruit juices, were analyzed for total polyphenol and anthocyanin contents, while the polyphenol content increased by 50–55%, a significant decrease of 38–46% in the anthocyanin content was detected (Kazazic et al., 2022). In another study, the stability of anthocyanins during the storage of syrups prepared from the *Kütahya* sour cherry variety was investigated. Over the 168-day storage period at 20 °C, the total anthocyanin content decreased by approximately 64% across all three types of syrup (sucrose, maltose syrup, and honey). However, when sour cherry nectar was sweetened with maltose syrup, the stabilities of C3GR and C3R increased by 8% and 4%, respectively, while the stability of C3G decreased by 11%, highlighting that the type of sugar can affect the stability of individual anthocyanins during storage (Ertan et al., 2018).

Jam quality is influenced by its recipe, processing methods, and storage conditions. In the process of jam preparation, a significant portion of polyphenolic compounds degrades. Even when jams are made from the same raw materials but with different combinations, the rate of phenolic compound degradation varies. After 8 months of storage, a 15–25% decrease in total polyphenol content can be expected, with the extent of this loss depending on the product's composition: lighter jams show a greater reduction in polyphenol content. The composition also significantly affects the anthocyanin content, with lighter jams experiencing a much greater decrease-up to nearly 90% (Vukoja et al., 2019).

An evaluation of total polyphenol and anthocyanin contents in jams made from four sour cherry cultivars (*Balaton*, *Kroeker*, *Northstar*, and *Karneol*) showed that total phenolic content decreased by 9% in *Balaton* and 15% in *Kroeker*, while *Northstar* exhibited a minimal, non-significant increase of 1.7%. No phenolic content data were available for *Karneol*. In contrast, total anthocyanin content decreased substantially, by approximately 75–79%, across all cultivars. In *Balaton* jam, analysis of individual anthocyanins revealed that C3GR and C3R were the main components in fresh fruit, which decreased from 109.7 and 13.8 mg/100 g FW to 5.2 and 1.1 mg/100 g FW in the jam, respectively, while C3G, peonidin 3-rutinoside, and the cyanidin derivative were nearly completely degraded (D. -O. Kim & Padilla-Zakour, 2004). In a study conducted over two consecutive years, the effects of individual processing steps on polyphenolic compounds were analyzed. After blanching and

Table 2 Health effects of compounds that also occur in sour cherry

Compound group	Subgroups/compounds	Biological activities	Reference
Flavonoids	**Anthocyanins**		
	Cyanidin-3-O-glucoside	Neuroprotective, anti-inflammatory, antioxidant, antioxidant & metabolism-improving, antioxidant & cytoprotective, endometrial protection, antiestrogenic, neuroprotective, reproductive protective effect	(Wang et al., 2016) (Ferrari et al., 2017) (Gowd et al., 2019) (Li et al., 2020) (Rahman et al., 2021) (Yang et al., 2022a, 2022b) (Baek et al., 2023) (Cai et al., 2023)
	Cyanidin-3-O-rutinoside	Chemoprotective, diabetes-preventive, cardiovascular-protective, anticancer, enhances insulin secretion, lipid-lowering, anti-inflammatory	(Feng et al., 2007) (Adisakwattana et al., 2011) (Thilavech et al., 2017) (Fragoso et al., 2018) (Kongthitilerd et al., 2022) (Thilavech & Adisakwattana, 2019) (Zhong et al., 2025) (Brunetti et al., 2023)
	Cyanidin-3-O-glucosylrutinoside	Antioxidant, anti-inflammatory, NF-κB inhibitor	(Kirakosyan et al., 2015) (Schlesinger et al., 2022)
	Flavonols		
	Quercetin derivatives		
	Quercetin-3-O-rutinoside *(rutin)*	Antioxidant, anticancer, lung-protective, antimicrobial, antibiofilm, anti-inflammatory, regulating apoptosis, kidney-protective, alleviates diabetic complications, senomorphic agent, anticancer potential, analgesic	(Imani et al., 2021) (Verma et al., 2022) (Yarmolinsky et al., 2022) (Dutta & Dahiya, 2023) (Dong et al., 2023) (Liu et al., 2024) (Forouzanfar et al., 2025)
	Quercetin-3-O-glucoside *(isoquercetin)*	Mitigates metabolic syndrome, reduces vascularization, modulates VASH1 & VASH2, anticancer activity, anti-aging, neuroprotection, anti-inflammatory, regulates intracellular Ca^{2+}, liver protection, reduces insulin resistance, regulates lipid metabolism, galectin-3 inhibition, cardioprotective, apoptosis inhibition, stabilizes mitochondrial membrane, regulates Phlpp1/AKT/Bcl-2 signaling, induces ferroptosis, suppresses NF-κB & AMPK, inhibits tumor growth	(Khlifi et al., 2020) (da Silva et al., 2022) (Yu & Chen, 2023) (Guo et al., 2024) (Jin et al., 2024) (Wang et al., 2024) (Luo et al., 2024)
	Kaempferol derivatives		
	Kaempferol-3-O-glucoside	Improves metabolism and cognition	(Khlifi et al., 2020) (Liu et al., 2023)
	Kaempferol-3-O-rutinoside	Cytoskeleton collapse, mitochondrial dysfunction, apoptosis induction, anticancer effect, SIRT1 activation, increased glucose uptake, GLUT4 translocation, improved insulin sensitivity, antipyretic, accelerates IL-6 & TNF-α elimination	(Li et al., 2021a, 2021b) (Kashyap et al., 2023) (Zheng et al., 2024)

Table 2 (continued)

Compound group	Subgroups/compounds	Biological activities	Reference
Non-flavonoid polyphenols	**Phenolic acids**		
	Hydroxycinnamic acids		
	Chlorogenic acid	Anticancer, anxiolytic, antioxidant, cognitive protection, mood improvement, blood pressure reduction, gut-protective	(Belkaid et al., 2006) (Bouayed et al., 2007) (Kwon et al., 2010) (Cropley et al., 2012) (Mubarak et al., 2012) (Song et al., 2022)
	Neochlorogenic acid	Anti-inflammatory, AMPK/Nrf2 activator, reduces lipid accumulation, inhibits fatty acid & cholesterol synthesis, suppresses miR-34a, induces MCU-mediated calcium overload, prevents atherosclerosis, inhibits Ras/FAK, suppresses type 2 immune response, enhances HO-1 expression, improves oxidative stress	(Park et al., 2018) (Gao et al., 2020) (Yu et al., 2021) (Li et al., 2021a, 2021b) (Yang et al., 2022a, 2022b) (Cheng et al., 2025)

chopping, the total phenolic content (TPC) decreased. However, following the addition of sugar and boiling, TPC increased due to water evaporation and product concentration. Compared to the fresh fruit, the final jam still showed a slightly lower TPC, approximately 14–16% lower (Băetu et al., 2016). A similar trend was observed in the total polyphenol content of jam made from *Montgomery* sour cherries during processing, where the value decreased by approximately 46%. The total anthocyanin loss was nearly 37% (Picariello et al., 2017). Heat treatment and other processing steps generally lead to a loss of polyphenols; however, in some cases, the relative concentration of polyphenols can increase during jam preparation. The increase in polyphenol content was also associated with higher added sugar levels and a decrease in water content. In jams made from *Oblačinska* and *Maraskan* sour cherry varieties, the total polyphenol content increased by approximately 7–30% compared with that of fresh fruit, whereas the total anthocyanin content significantly decreased by 59–67% (Kazazic et al., 2022).

In sour cherry jams, further decreases in anthocyanin content were observed during 8 months of storage, both when the samples were stored in a refrigerator (+4 °C) and at room temperature (+20 °C). The decrease was proportional to the storage time. After 2 months, only an approximately 6% reduction was observed, whereas after 8 months, the decrease reached 28%. Storage at room temperature resulted in an average anthocyanin loss of 15.74%, whereas refrigerated storage resulted in a much lower decrease of only 6.91% (Koca & Ustun, 2009). After 3 months of storage, the total polyphenol content in sour cherry jam decreased by 18%, whereas the anthocyanin content decreased by 22% compared with the value measured one day after processing (Poiana et al., 2011).

Liqueurs made from several fruit species were analyzed, including sour cherry.

The samples were stored for 3 and 6 months at 15 °C and 30 °C. The total polyphenol content decreased by 36–55.8%, and the anthocyanin content decreased by 62.94–94.3% in sour cherry liqueurs after 6 months. Before storage, the two main anthocyanins, C3GR and C3R, accounted for 62.2% and 25.6% of the total anthocyanin content, respectively. After storage at 30 °C, their relative contributions were 66.0% and 21.4%, indicating that C3GR, containing three sugar moieties, was more stable than C3R, which has two sugar units (Sokół-Łętowska et al., 2014).

Sour cherry purees with different sweeteners—including erythritol, sucrose, palm sugar, xylitol, Luo Han Kuo fruit, inulin, and steviol glycoside—were stored for 6 months at 4 °C and 30 °C. Total polyphenol content ranged from 725.6 to 1179.6 mg/100 g DW, while total anthocyanins ranged from 97.6 to 149.8 mg/100 g DW. The results showed that polyphenol and anthocyanin levels decreased during storage, with lower losses at 4 °C and higher losses at 30 °C, depending on the type of sweetener. Analysis of individual anthocyanins in the sour cherry purees revealed six compounds, with C3GR, C3R, and cyanidin-3-O-sophoroside as the main components.

C3G and peonidin-3-O-rutinoside were also detected. Storage at 4 °C for 6 months did not affect the qualitative composition of the anthocyanin fractions. However, storage at 30 °C led to complete loss of cyanidin-3-O-xylosylrutinoside in all samples, and peonidin-3-O-rutinoside was lost in samples without added sweetener and with sucrose (Nowicka & Wojdyło, 2016).

The total anthocyanin content in the sour cherry liqueurs was 216.8–230.8 μg/ml. After 24 weeks of storage, anthocyanin levels decreased significantly, reaching 39–40% of the initial value in samples stored at 15 °C and 6.5–6.9% at 30 °C. The total phenolic content was 1.15 mg GAE/ml before storage and, after 24 weeks, decreased slightly to 1.10–1.14 mg GAE/ml in sugar-free liqueurs, while it increased to 1.21–1.25 mg GAE/ml in sugar-containing liqueurs. These results indicate that, although anthocyanins degraded rapidly during storage, flavonoids and other phenolic compounds remained relatively stable, and the presence of sugar may have contributed to an apparent increase in TPC due to the transformation of phenolic compounds (Sokół-Łętowska et al., 2018).

The anthocyanin content of freeze-dried sour cherries decreases during storage. The stability of anthocyanins in freeze-dried cherries stored under ambient conditions is strongly influenced by the storage temperature. While storage at 4 °C resulted in a 30% decrease, storage at 37 °C led to complete degradation. This trend was also observed in spray-dried and stored products; however, even one year after drying at 4 °C, a 60–70% decrease was noted, whereas at 37 °C, approximately 10% of the anthocyanin content was still detectable. Lower storage temperatures prolong shelf-life and better preserve color and sensory properties (Zorić et al., 2016, 2017).

In one study, fresh sour cherries and their freeze-dried counterparts were examined to evaluate the effects of lyophilization on bioactive compounds. The total phenolic content (TPC) of fresh sour cherries was 1,150 mg GAE/100 g DW, while freeze-dried samples measured 1,283 mg GAE/100 g DW; however, this increase was not statistically significant. Similarly, the flavonoid content showed no significant difference between fresh and freeze-dried cherries, indicating that lyophilization preserves these compounds effectively (Topa et al., 2021).

In a recent study, pitted sour cherries (cv. Amarena del Rio) were treated with high-pressure processing (HPP, 600 MPa, 3 min at 4 °C). Compared to the untreated control, the total polyphenol content slightly decreased from 11.69 to 11.54 mg GAE/g, corresponding to a 1% reduction, which was not statistically significant. The total flavonoid content increased from 1.32 to 1.75 mg QE/g, representing a 32% increase over the control, which was statistically significant. Total anthocyanins decreased from 10.63 to 9.47 mg C3G/g, corresponding to an 10.9% reduction, which was not significant. These results indicate that HPP preserves the major bioactive compounds in sour cherries, with minimal losses in polyphenols and anthocyanins and a significant increase in flavonoids compared to untreated fruit (Tenuta et al., 2023).

The pulsed electric field (PEF) treatments did not significantly affect the total phenolic content (TPC) or total monomeric anthocyanin content (TMAC) of sour cherry juice, with TPC values ranging from 548.83 ± 59.65 mg GAE/L (0.0020 J/L) to 643.23 ± 60.17 mg GAE/L (0.0034 J/L), while TMAC values showed no significant change across the different PEF treatments. In addition, the initial cyanidin-3-O-sophoroside and C3G concentrations did not change significantly with the PEF treatments. The C3GR concentrations decreased by only 0.2–3.4%, while the C3R concentrations decreased by 0.2–1.2%, indicating that the individual anthocyanins remained stable (Akdemir Evrendilek et al., 2020).

Fresh sour cherry juice was treated using a combined ACP-PEF system to reduce microbial load while preserving bioactive compounds. PEF was applied at 5–10 kV/cm with 5–35 s pulse duration, followed by atmospheric cold plasma (ACP) treatment using 6–20 kHz frequency and 0–20 kV voltage. The treatment caused minimal changes in total phenolic content (TPC decreased 3–8%) and total monomeric anthocyanin content (TAC decreased up to 6%), significantly lower than the 16% anthocyanin loss observed during conventional thermal pasteurization (Jamali-Hafshejani et al., 2025).

Vacuum-dried sour cherry extracts were subjected to non-thermal ultrasound-assisted extraction (UAE) at temperatures between 40 and 80 °C, using ultrasonic power levels of 30–60 W/L. The total polyphenol content of the extracts ranged from 1.16 to 1.96 g GAE/100 g, showing that higher temperature and optimal liquid-to-solid ratios enhanced polyphenol recovery. The total flavonoid content varied between 0.60 and 0.87 g CE/100 g, with the highest values obtained at 60 °C and 40% ethanol concentration. The total monomeric anthocyanin content ranged from 9.80 to 30.17 mg C3G/100 g, reaching its maximum at 80 °C with 40% ethanol and a 10 mL/g liquid-to-solid ratio. Overall, temperature and solvent ratio were found to be the key factors influencing the extraction efficiency of bioactive compounds (Milić et al., 2021). An osmotic dehydration (OD) study was conducted on four types of sour cherries (cv. *Turgieniewka*) to evaluate changes in polyphenolic content and antioxidant activity. The samples included frozen and thawed cherries, both with and without stones. Apple concentrate (40°Brix, 40 °C) was used as the osmotic solution at a fruit-to-solution ratio of 1:2, and the process lasted 180 min. Results showed that OD led to a significant decrease in total polyphenols, particularly during the first

60 min. The greatest loss was observed in thawed without stones (TW), with a 47.4% reduction relative to fresh fruit, while frozen with stones (FS) retained the highest polyphenol content, showing only a 16.9% decrease. In the combined OD-CD-VMD process, sour cherries were first subjected to osmotic dehydration (OD), followed by convective drying (CD) and final vacuum-microwave drying (VMD). CD uses warm air (50 °C) to partially dry the fruit, while VMD applies microwaves under vacuum to achieve final dehydration at lower temperatures, minimizing heat damage. Polyphenol loss was minimal compared with the OD-only process: the FS sample lost only 16.96%, and (frozen without stone) FW 16.4%, whereas in the OD-only study the TW sample lost as much as 47.4%. This shows that the combined method better preserves polyphenols and antioxidant activity (Nowicka et al., 2015). Nectar was produced from the "*Kutahya*" sour cherry variety. In the final nectar, total phenolics decreased by 64%, flavonoids by 39%, and anthocyanins by 55% compared to fresh fruit. In vitro digestion indicated that anthocyanins were fivefold more bioavailable in the nectar, likely due to the stabilizing effect of added sugar (Toydemir et al., 2013). Spray-dried sour cherry juice concentrate was studied for the effects of inlet temperature, feed rate, fruit content, and carrier type. Fruit content and carrier type significantly affected total phenolic content, with gum arabic providing better protection than maltodextrin. Depending on the conditions, total phenolics decreased by approximately 12–20% (Can Karaca et al., 2016).

Tables 3 and 4 summarize the effects of storage and processing on different sour cherry cultivars and their derived products.

Table 3 Effects of storage and processing on the polyphenol content of sour cherries. Abbreviations: DW – dry weight; FW – fresh weight; GAE – gallic acid equivalents; C3G – cyanidin-3-O-glucoside

Storage/Processing	Key points of the article	Measured compounds	Decrease (%)	Reference
Storage	Sour cherry jam stored for 8 months at room temperature (+ 20 °C) and in the fridge (+ 4 °C)	Total anthocyanin content (mg/kg)	5.79–28.20%	(Koca & Ustun, 2009)
	Thermal processing and storage time effect on low-sugar sour cherry jam	Total phenolics losses (%)	8.98–18.2%	(Poiana et al., 2011)
		Monomeric anthocyanin losses (%)	9.56–21.57%	
	Sour cherry liqueurs, stored for 3 and 6 months 15 °C, 30 °C (sugar; without sugar)	Total phenolic content (mg/100 ml FW)	36–55.8%	(Sokół-Łętowska et al., 2014)
		Total anthocyanin content (mg C3G/100 ml FW)	62.94–94.3%	
	Freeze-dried sour cherry; two types of packaging, one with aluminum layer, storage 12 months, temperatures 4, 20, and 37 °C	Total anthocyanin content (mg/100 g DW)	4.23–100%	(Zorić et al., 2016)
	Spray-dried sour cherry powder; two types of packaging, one with aluminum layer, storage 12 months, temperatures 4, 20, and 37 °C	Total anthocyanin content (mg/100 g DW)	5.49–90.18%	(Zorić et al., 2017)
	Concentrated sour cherry juice (−18 °C storage for 2 months), nectar storage: 168 days at 20 °C	Total anthocyanin content (mg/L FW)	64%	(Ertan et al., 2018)
	Jam storage: 8 months at room temperature; samples: (1) regular jam (2) extra jam (3) light jam	Total phenolic content (g GAE/kg)	14.84–25.74%	(Vukoja et al., 2019)
		Total monomeric anthocyanin content (mg C3G/kg)	77.48–87.4%	
		Total anthocyanins (mg C3G/100 g FW)	38.79–46.75%	
	Sour cherry puree (with palm sugar, erythritol, xylitol, inulin, steviol glycoside) Duration: 6 months 4 °C and 30 °C	Total phenolic content (mg/100 g DW)	4–39%	(Nowicka & Wojdyło, 2016)
		Total anthocyanins	7–54%	
	Sour cherry liqueurs: sugar-containing and sugar-free variants Duration: 6 months (24 weeks) 15 °C and 30 °C	Total anthocyanins (µg/ml FW)	6.5–40%	(Sokół-Łętowska et al., 2018)
		Total phenolic content (mg GAE/ml FW)	1–4% **(+ 5 – 9%)**	

Table 4 Effects of processing on the polyphenol content of sour cherries. Abbrevations: FW – fresh weight; DW – dry weight; GAE – gallic acid equivalents; CE – catechin equivalents; C3G – cyanidin-3-O-glucoside; C3GE – cyanidin-3-O-glucoside equivalents; QE – quercetin equivalents; PEF – pulsed electric fields; ACP – atmospheric cold plasma; HPP – high pressure processing; UAE – ultrasound assisted extraction; MAE – microwave assisted extraction; OD – osmotic dehydration, FS – frozen sour cherries with stones; FW (in this study: (Nowicka et al., 2015)– frozen sour cherries without stones; TS – thawed sour cherries with stones; TW – thawed sour cherries without stones; CD – convective drying; VMD –vacuum-microwave finish drying. Values in bold indicate an increase in the measured parameters

Storage/Processing	Key points of the article	Measured compounds	Decrease (%)	Reference
Thermal processing (sour cherry jam)	4 sour cherry varieties, jam: 50% fruit, 48% sugar, 2% pectin mixture (dextrose, pectin, fumaric acid), 65–68°Brix	Total phenolic content (mg GAE/100 g FW)	0–15.43%	(Kim & Padilla-Zakour, 2004)
		Total anthocyanin content (mg C3G/100 g FW)	75.44–79.11%	(Kim & Padilla-Zakour, 2004)
	Jam production: total polyphenols measured during different technological steps	Total content of polyphenols (mg GAE/100 g FW)	14.4–16.2%	(Băetu et al., 2016)
	Jam preparation: 500 g pitted cherries + 25 g pectin + 200 g sucrose, 62.5–65°Brix	Total phenolic content (mg GAE/100 g FW → mg GAE/100 g jam)	46.46%	(Picariello et al., 2017)
		Total anthocyanin content (mg C3GE/100 g FW → mg C3GE/100 g jam)	36.84%	
	Jam preparation: traditional recipe, 2 cherry cultivars	Total phenolic content (mg GAE/100 g FW)	**+7.49** – **30.4%**	(Kazazic et al., 2022)
		Total anthocyanin content (mg C3G/100 g FW)	59.52–67.68%	
Thermal processing (sour cherry nectar)	Product: cherry nectar, 22-step process	Total flavonoid content (mg CE/100 g DW)	38.78%	(Toydemir et al., 2013)
		Total anthocyanin content (mg C3G/100 g DW)	55.47%	
Thermal processing (sour cherry juice)	Product: cherry juice from two cherry cultivars, thermal processing 4 h at 70, 80, and 90 °C	Total anthocyanin content (mg C3G/L FW)	1.75–45.80%	(Szalóki-Dorkó & Végvári 2015)
	Homemade cherry juice heat treatment: 250 g cherries + 750 ml drinking water + 50 g sugar, heat to 13–13.5 Brix, heating: 70–75 °C for 20 min, boiling 10 min, microwave 22 min	Total monomeric anthocyanin (mg/L FW)	2.97–53.69%	(Yıldız et al., 2022)
	Fruit juice production: traditional recipe, 2 cherry cultivars	Total phenolic content (mg GAE/100 g FW)	**+50.96** – **55.03%**	(Kazazic et al., 2022)
		Total anthocyanins (mg C3G/100 g FW)	38.79–46.75%	
Non-thermal processing- high-pressure processing	Fresh pitted sour cherries (cv. Amarena del Rio) with 15.78°Brix and 22.15 g/L acidity were processed using high-pressure processing (HPP, 600 MPa, 3 min, 4 °C)	Total phenolic content (mg GAE/g)	1.28% no significant change	(Tenuta et al., 2023)
		Total flavonoid content (mg QE/g)	**+32%**	
		Total monomeric anthocyanin content (mg C3G/g)	10.9% no significant change	
Non-thermal processing- pulsed electric fields (sour cherry juice)	Fresh sour cherry juice (13°Brix) was processed using pulsed electric fields (PEF) with bipolar square-wave pulses of 3 µs duration, 0–26.7 kV/cm electric field strength, 0–0.0341 J/L energy, and 0–500 pps frequency	Total phenolic content (mg GAE/L FW)	no significant change	(Akdemir Evrendilek et al., 2020)
		Total monomeric anthocyanin content (mg/L FW)	no significant change	

Table 4 (continued)

Storage/Processing	Key points of the article	Measured compounds	Decrease (%)	Reference
Non-thermal processing- atmospheric cold plasma + pulsed electric fields (sour cherry juice)	Fresh sour cherries were processed into juice PEF was applied at 5–10 kV/cm for 5–35 s, followed by ACP at 6–20 kHz and 0–20 kV	Total phenolic content (mg GAE/100 g FW)	3–8%	(Jamali-Hafshejani et al., 2025)
		Total monomeric anthocyanin content (mg/L FW)	6%	
Non-thermal processing (freeze-drying)	Fresh sour cherries, freeze-drying, −45 °C, 24–48 h	Total phenolic content (mg GAE/100 g DW)	12% no significant change	(Topa et al., 2021)
		Total flavonoid content (mg CE/100 g DW)	no significant change	
Non-thermal processing-vacuum-dried sour cherry	Vacuum-dried sour cherry, non-thermal ultrasound-assisted extraction (UAE) 40–80 °C 20–40 min, 30–60 W/L	Total phenolic content (g GAE/100 g DW)	**+69%**	(Milić et al., 2021)
		Total flavonoid content (g CE/100 g DW)	**+45%**	
		Total monomeric anthocyanin content (mg C3G/100 g DW)	**+208%**	
Non-thermal processing (osmotic dehydration)	Sour cherry (cv. *Turgieniewka*) Frozen/Thawes; stones/without stone (FS, FSW, TS, TW) OD: Apple concentrate diluted to 40°Brix, heated to 40 °C before adding fruit Fruit:solution ratio = 1:2	Total phenolic content (mg GAE/100 g DW)	16.92–47.40%	(Nowicka et al., 2015)
Non-thermal and thermal processing (osmotic dehydration—convective drying—vacuum-microwave finish drying)	Sour cherry (cv. *Turgieniewka*) (FS, FW) CD: 50 °C, 90 min VMD: 360 W	Total phenolic content (mg GAE/100 g DW)	16.4–16.96%	
Thermal processing- Spray drying (sour cherry concentrate)	Sour cherry concentrate (65°Brix) Spray drying 130–150 °C Materials: maltodextrin and gum arabic	Total phenolic content (mg GAE/100 g DW)	11.7–19.6%	(Can Karaca et al., 2016)
	Sour cherry (cv. *Marasca, Oblačinska*) concentrate (65°Brix) Heat treatment 45–85 °C, enzymatic treatment and pasteurization	Total phenolic content (mg GAE/g DW)	**+32.59–37.71%**	(Repajić et al., 2015)
		Total monomeric anthocyanin content (mg C3G/g DW)	**+25.18–57.72%**	
Thermal processing (sour cherry nectar)	Sour cherry nectar (cv. *Kütahya*) 17 steps processing Analysis method: in vitro gastrointestinal digestion	Total phenolic content (mg GAE/100 g DW)	64%	(Toydemir et al., 2013)
		Total flavonoid content (mg CE/100 g DW)	61%	
		Total anthocyanins (mg C3GE/100 g DW)	45%	

Conclusion

Among the bioactive constituents of sour cherries, polyphenolic compounds are considered particularly important due to their abundance and diverse biological activities, with their levels showing considerable variability depending on genetic, cultivation, and environmental factors. Flavonoids, particularly anthocyanins (notably cyanidin derivatives), constitute the largest proportion, determining the characteristic color of the fruit and contributing substantially to its antioxidant capacity. Flavonols – mainly quercetin and kaempferol derivatives – are present in smaller amounts, yet they play an important role in the biological activity. Among the nonflavonoid polyphenols, chlorogenic and neochlorogenic acids are the most prominent.

The various polyphenolic compounds present in sour cherries may exert numerous beneficial physiological effects. It is important to note that the health-related effects discussed in this review, such as anti-inflammatory, antioxidant, neuroprotective, and other activities, are not exclusively based on studies conducted with sour cherries, but also include findings from other plant sources containing similar compounds. This is partly due to the relatively limited number of animal and human studies on isolated polyphenols from sour cherries, resulting in a scarcity of clinical data directly assessing the effects of sour cherry consumption on human health.

Not only genetic and environmental factors, but also storage and processing methods fundamentally influence the polyphenolic composition and concentration in sour cherries. Thermal treatment, processing steps, and storage conditions all contribute to a reduction in bioactive compound levels, which may affect the nutritional and health-promoting value of cherry-based products. Based on current knowledge, the polyphenolic profile of sour cherries is exceptionally rich, yet it is highly responsive to various external factors, which is a critical consideration for practical applications and industrial processing.

Several processing and storage methods have been shown to better preserve polyphenolic compounds in sour cherries and their products. Conventional heat treatments generally reduce polyphenol content, while non-thermal techniques, such as high-pressure processing (HPP), pulsed electric fields (PEF), and atmospheric cold plasma (ACP), result in minimal. Freeze-drying (lyophilization) effectively maintain both total phenolics and anthocyanins, especially when stored at low temperatures (4 °C), whereas storage at higher temperatures accelerates degradation. Ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE), and osmotic dehydration combined with convective and vacuum-microwave drying (OD-CD-VMD) improve polyphenol recovery and reduce heat-induced degradation. The addition of sugar during nectar or jam production can stabilize anthocyanins and increase the apparent concentration of polyphenols due to water evaporation and concentration effects. Overall, non-thermal or combined processing methods, low-temperature storage, and sugar addition are effective strategies to maintain polyphenol content in sour cherry products.

Future research should prioritize the detailed investigation of the stability, bioavailability, and physiological effects of polyphenolic compounds in sour cherries. While current evidence supports the potential health-promoting effects of sour cherries, including antioxidant, anti-inflammatory, and cardioprotective activities, a greater number of clinical studies specifically focusing on sour cherries are needed to more firmly establish their benefits in humans. Large-scale, well-designed human trials evaluating the effects of regular sour cherry consumption on physiological outcomes are warranted. In addition, investigations into the impact of different processing and storage methods are essential, as these factors critically influence the concentration of bioactive compounds and, consequently, the functional value of cherry-derived products. In future studies, the investigation of the bioavailability in vivo and in vitro human gastrointestinal digestion of sour cherries and their derived products (e.g., jams) could provide valuable insights into the metabolic fate and biological activity of their bioactive compounds. Furthermore, in addition to processing technology, it would be worthwhile to investigate the effects of different additives on sour cherry products. For example, during enrichment with various amino acids or dietary fibers, it would be important to evaluate how these additives influence or preserve the high biological value of sour cherries.

Abbreviations

ACP	Atmospheric cold plasma
AMPK	AMP-activated protein kinase
AP	Acai pulp
BEAS-2B	Human airway epithelial cells
C3G	Cyanidin-3-O-glucoside
C3GE	Cyanidin-3-O-glucoside equivalent
C3GR	Cyanidin-3-O-glucosylrutinoside
C3R	Cyanidin-3-O-rutinoside
Caco-2	Human adenocarcinoma cells
CE	Catechin equivalent
CGA	Chlorogenic acid
CNE1 cells	Human nasopharyngeal carcinoma cells
DKD	Diabetic kidney disease
DNA	Deoxyribonucleic acid
DW	Dry weight
FA	Ferulic acid
FAK	Focal adhesion kinase
FASN	Fatty acid synthase
FS	Frozen Sour cherries with stones
FW (in this study (Nowicka et al., 2015))	Frozen Sour cherries without stones
FW	Fresh weight
G6PT	Glucose-6-phosphate translocase

GAE	Gallic acid equivalent
GLUT4	Glucose transporter 4
HepG2 cells	Human hepatoma cell line
HFD	High-fat diet
HL-60	Human promyelocytic leukemia cells
HMG-CoA	3-Hydroxy-3-methylglutaryl-coenzyme A
HNE1 cells	Human nasopharyngeal carcinoma cells
HPP	High pressure processing
IL-1β	Interleukin-1β
INS-1 cells	Rat insulinoma beta cells
IQ	Isoquercitrin
JNK	C-Jun N-terminal kinase
K3G	Kaempferol-3-O-glucoside
K3R	Kaempferol-3-O-rutinoside
L6 cells	Rat skeletal muscle cells
MAE	Microwave assisted extraction
MAPK	Mitogen-activated protein kinase
MCU	Mitochondrial calcium uniporter
MLE	Mulberry leaf extract
MS	Metabolic syndrome
NAFLD	Nonalcoholic fatty liver disease
NF-κB/TGF-β1	Nuclear factor kappa B / transforming growth factor beta 1
NF-κB	Nuclear factor kappa B
NLRP3	Pyrin domain-containing protein 3
Nrf2/ARE	Nuclear factor erythroid 2-related factor 2 / antioxidant response element
Nrf2/HO-1	Nuclear factor erythroid 2-related factor 2/heme oxygenase-1
OD	Osmotic Dehydration
PCA	Protocatechuic acid
PEF	Pulsed electric fields
PI3K	Phosphoinositide 3-kinase
Q3G	Quercetin-3-O-glucoside
Q3R	Quercetin-3-O-rutinoside
QE	Quercetin equivalents
ROS	Reactive oxygen species
SAMP8	Senescence-accelerated mouse prone 8
SIRT1	Sirtuin 1
SREBP1	Sterol regulatory element-binding protein 1
SREBP2	Sterol regulatory element-binding protein 2
T2DM	Type 2 diabetes mellitus
TEER	Transepithelial electrical resistance
THTF	*Tetrastigma hemsleyanum* Total flavonoids
TNF-α	Tumor necrosis factor alpha
TS	Thawed Sour cherries with stones
TW	Thawed Sour cherries without stones UAE: ultrasound assisted extraction
VSMCs	Vascular smooth muscle cells

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Declarations

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References

Adisakwattana, S., Yibchok-Anun, S., Charoenlertkul, P., & Wongsasiripat, N. (2011). Cyanidin-3-rutinoside alleviates postprandial hyperglycemia and its synergism with acarbose by inhibition of intestinal α-glucosidase. *Journal of Clinical Biochemistry and Nutrition*, *49*(1), 36–41. https://doi.org/10.3164/jcbn.10-116

Akdemir Evrendilek, G., Ağçam, E., & Akyildiz, A. (2020). Effects of pulsed electric fields on sour cherry juice properties and formations of furfural and hydroxymethylfurfural. *International Journal of Food Engineering*, *1*. https://doi.org/10.1515/ijfe-2020-0189

Alappat, B., & Alappat, J. (2020). Anthocyanin pigments: Beyond aesthetics. *Molecules (Basel, Switzerland)*, *25*(23), 5500. https://doi.org/10.3390/molecules25235500

Baek, H., Sanjay, Park, M., & Lee, H.-J. (2023). Cyanidin-3-O-glucoside protects the brain and improves cognitive function in APPswe/PS1ΔE9 transgenic mice model. *Journal of Neuroinflammation*, *20*(1), 268. https://doi.org/10.1186/s12974-023-02950-3

Băetu, A.-L., Patraş, A., Băetu, M.-M., & Ghendov-Moşanu, A. (2016). Jam processing effects on ascorbic acid, phenolic compounds and enzymatic activities in sour cherry fruits. In Modern Technologies in the Food Industry (pp. 111–116). Chişinău, Moldova. https://ibn.idsi.md/vizualizare_articol/81327

Belkaid, A., Currie, J.-C., Desgagnés, J., & Annabi, B. (2006). The chemopreventive properties of chlorogenic acid reveal a potential new role for the microsomal glucose-6-phosphate translocase in brain tumor progression. *Cancer Cell International*, *6*(1), 7. https://doi.org/10.1186/1475-2867-6-7

Blando, F., & Oomah, B. D. (2019). Sweet and sour cherries: Origin, distribution, nutritional composition and health benefits. *Trends in Food Science & Technology*, *86*, 517–529. https://doi.org/10.1016/j.tifs.2019.02.052

Blando, F., Gerardi, C., & Nicoletti, I. (2004). Sour cherry (*Prunus cerasus* L) anthocyanins as ingredients for functional foods. *BioMed Research International, 2004*(5), 253–258. https://doi.org/10.1155/S1110724304404136

Bobrysheva, T. N., Anisimov, G. S., Zolotoreva, M. S., Bobryshev, D. V., Budkevich, R. O., & Moskalev, A. A. (2023). [Polyphenols as promising bioactive compounds]. *Voprosy Pitaniia*, *92*(1), 92–107. https://doi.org/10.33029/0042-8833-2023-92-1-92-107

Bouayed, J., Rammal, H., Dicko, A., Younos, C., & Soulimani, R. (2007). Chlorogenic acid, a polyphenol from *Prunus domestica* (Mirabelle), with coupled anxiolytic and antioxidant effects. *Journal of the Neurological Sciences, 262*(1–2), 77–84. https://doi.org/10.1016/j.jns.2007.06.028

Brunetti, L., Wang, L., Wassef, A., Gong, Y., Brinker, A., Buckley, B., Lipsky, P. E., Ondar, P., Poiani, G., Zhao, L., Kong, A., & Schlesinger, N. (2023). Pharmacokinetics and pharmacodynamics of anthocyanins after administration of tart cherry juice to individuals with gout. *Molecular Nutrition & Food Research, 67*(9), 2200550. https://doi.org/10.1002/mnfr.202200550

Cai, D., Li, X., Xu, Q., Li, H., Liu, R., Chen, J., Jiang, X., Sun, J., Lai, C., & Bai, W. (2023). Cyanidin-3-*O*-glucoside and protocatechuic acid alleviate heat stress-induced testicular damage. *Food & Function, 14*(4), 2200–2211. https://doi.org/10.1039/D2FO03423A

Can Karaca, A., Guzel, O., & Ak, M. M. (2016). Effects of processing conditions and formulation on spray drying of sour cherry juice concentrate. *Journal of the Science of Food and Agriculture, 96*(2), 449–455. https://doi.org/10.1002/jsfa.7110

Cheng, S.-C., Liou, C.-J., Wu, S.-J., Lin, C.-F., Huang, T.-H., & Huang, W.-C. (2025). Neochlorogenic acid ameliorates allergic airway inflammation by suppressing type 2 immunity and upregulating HO-1 expression. *International Immunopharmacology, 146*, 113867. https://doi.org/10.1016/j.intimp.2024.113867

Ciupei, D., Colişar, A., Leopold, L., Stănilă, A., & Diaconeasa, Z. M. (2024). Polyphenols: From classification to therapeutic potential and bioavailability. *Foods, 13*(24), 4131. https://doi.org/10.3390/foods13244131

Cropley, V., Croft, R., Silber, B., Neale, C., Scholey, A., Stough, C., & Schmitt, J. (2012). Does coffee enriched with chlorogenic acids improve mood and cognition after acute administration in healthy elderly? A pilot study. *Psychopharmacology (Berl), 219*(3), 737–749. https://doi.org/10.1007/s00213-011-2395-0

da Silva, DdeC., Orfali, G. D. C., Santana, M. G., Palma, J. K. Y., Assunção, IRdeO., Marchesi, I. M., Grizotto, A. Y. K., Martinez, N. P., Felliti, S., Pereira, J. A., & Priolli, D. G. (2022). Antitumor effect of isoquercetin on tissue vasohibin expression and colon cancer vasculature. *Oncotarget, 13*, 307–318. https://doi.org/10.18632/oncotarget.28181

Dias, M. C., Pinto, D. C. G. A., & Silva, A. M. S. (2021). Plant flavonoids: Chemical characteristics and biological activity. *Molecules, 26*(17), 5377. https://doi.org/10.3390/molecules26175377

Dong, R., Zhang, X., Liu, Y., Zhao, T., Sun, Z., Liu, P., Xiang, Q., Xiong, J., Du, X., Yang, X., Gui, D., & Xu, Y. (2023). Rutin alleviates EndMT by restoring autophagy through inhibiting HDAC1 via PI3K/AKT/mTOR pathway in diabetic kidney disease. *Phytomedicine, 112*, 154700. https://doi.org/10.1016/j.phymed.2023.154700

Dutta, A., & Dahiya, A. (2023). Quercetin 3-O rutinoside prevents gastrointestinal injury through regulation of apoptosis in 7.5 Gy total body irradiated mice. *Phytomedicine, 112*, 154692. https://doi.org/10.1016/j.phymed.2023.154692

Ertan, K., Türkyılmaz, M., & Özkan, M. (2018). Effect of sweeteners on anthocyanin stability and colour properties of sour cherry and strawberry nectars during storage. *Journal of Food Science and Technology, 55*(10), 4346–4355. https://doi.org/10.1007/s13197-018-3387-4

Feng, R., Ni, H.-M., Wang, S. Y., Tourkova, I. L., Shurin, M. R., Harada, H., & Yin, X.-M. (2007). Cyanidin-3-rutinoside, a natural polyphenol antioxidant, selectively kills leukemic cells by induction of oxidative stress. *Journal of Biological Chemistry, 282*(18), 13468–13476. https://doi.org/10.1074/jbc.M610616200

Ferrari, D., Cimino, F., Fratantonio, D., Molonia, M. S., Bashllari, R., Busà, R., Saija, A., & Speciale, A. (2017). Cyanidin-3-o-glucoside modulates the in vitro inflammatory crosstalk between intestinal epithelial and endothelial cells. *Mediators of Inflammation, 2017*, 1–8. https://doi.org/10.1155/2017/3454023

Food and Agriculture Organization of the United Nations. (2023). FAOSTAT statistical database. https://www.fao.org/faostat/

Forouzanfar, F., Sahranavard, T., Tsatsakis, A., Iranshahi, M., & Rezaee, R. (2025). Rutin: A pain-relieving flavonoid. *Inflammopharmacology*. https://doi.org/10.1007/s10787-025-01671-8

Fragoso, M. F., Romualdo, G. R., Vanderveer, L. A., Franco-Barraza, J., Cukierman, E., Clapper, M. L., Carvalho, R. F., & Barbisan, L. F. (2018). Lyophilized açaí pulp (*Euterpe oleracea* Mart) attenuates colitis-associated colon carcinogenesis while its main anthocyanin has the potential to affect the motility of colon cancer cells. *Food and Chemical Toxicology, 121*, 237–245. https://doi.org/10.1016/j.fct.2018.08.078

Gao, X., Zhang, S., Wang, L., Yu, L., Zhao, X., Ni, H., Wang, Y., Wang, J., Shan, C., & Fu, Y. (2020). Anti-inflammatory effects of neochlorogenic acid extract from mulberry leaf (*Morus alba* L.) against LPS-stimulated inflammatory response through mediating the AMPK/Nrf2 signaling pathway in A549 cells. *Molecules, 25*(6), 1385. https://doi.org/10.3390/molecules25061385

Głowacka, A., Rozpara, E., & Hallmann, E. (2020). The dynamic of polyphenols concentrations in organic and conventional sour cherry fruits: Results of a 4-year field study. *Molecules, 25*(16), 3729. https://doi.org/10.3390/molecules25163729

Gowd, V., Bao, T., & Chen, W. (2019). Antioxidant potential and phenolic profile of blackberry anthocyanin extract followed by human gut microbiota fermentation. *Food Research International, 120*, 523–533. https://doi.org/10.1016/j.foodres.2018.11.001

Guo, T., Chen, G., Yang, L., Deng, J., & Pan, Y. (2024). Piezo1 inhibitor isoquercitrin rescues neural impairment mediated by NLRP3 after intracerebral hemorrhage. *Experimental Neurology, 379*, 114852. https://doi.org/10.1016/j.expneurol.2024.114852

Imani, A., Maleki, N., Bohlouli, S., Kouhsoltani, M., Sharifi, S., & Maleki Dizaj, S. (2021). Molecular mechanisms of anticancer effect of rutin. *Phytotherapy Research, 35*(5), 2500–2513. https://doi.org/10.1002/ptr.6977

Jamali-Hafshejani, F., Hosseinzadeh Samani, B., Taki, K., & Ghatrehsamani, S. (2025). Design, construction, and evaluation of a combined atmospheric cold plasma-pulsed electric field spraying system for pasteurization of sour cherry juice. *Food Science & Nutrition, 13*(6), e70465. https://doi.org/10.1002/fsn3.70465

Jin, H.-L., Feng, X.-Y., Feng, S.-L., Dai, L., Zhu, W.-T., & Yuan, Z.-W. (2024). Isoquercitrin attenuates the progression of non-alcoholic steatohepatitis in mice by modulating galectin-3-mediated insulin resistance and lipid metabolism. *Phytomedicine : International Journal of Phytotherapy and Phytopharmacology, 123*, 155188. https://doi.org/10.1016/j.phymed.2023.155188

Karaaslan, N. M., & Yaman, M. (2016). Determination of anthocyanins in cherry and cranberry by high-performance liquid chromatography–electrospray ionization–mass spectrometry. *European Food Research and Technology, 242*(1), 127–135. https://doi.org/10.1007/s00217-015-2524-9

Kashyap, B., Saikia, K., Samanta, S. K., Thakur, D., Banerjee, S. K., Borah, J. C., & Talukdar, N. C. (2023). Kaempferol 3-O-rutinoside *az Antidesma acidum* Retz-től. Stimulálja a glükózfelvételt a SIRT1 indukción keresztül, amit GLUT4 transzlokáció követ a vázizom L6 sejtekben. *Journal of Ethnopharmacology*, *301*, 115788. https://doi.org/10.1016/j.jep.2022.115788

Kazazić, M., Mehić, E., & Djapo-Lavić, M. (2022). Phenolic content and bioactivity of two sour cherry cultivars and their products. *Glasnik Hemijskih Tehnologa Bosne i Hercegovine, 58*(1), 1–6. https://doi.org/10.35666/2232-7266.2021.58.01

Khlifi, R., Dhaouefi, Z., Toumia, I. B., Lahmar, A., Sioud, F., Bouhajeb, R., Bellalah, A., & Chekir-Ghedira, L. (2020). *Erica multiflora* extract rich in quercetin-3-*O*-glucoside and kaempferol-3-*O*-glucoside alleviates high fat and fructose diet-induced fatty liver disease by modulating metabolic and inflammatory pathways in Wistar rats. *The Journal of Nutritional Biochemistry, 86*, 108490. https://doi.org/10.1016/j.jnutbio.2020.108490

Khoo, G. M., Clausen, M. R., Pedersen, B. H., & Larsen, E. (2011). Bioactivity and total phenolic content of 34 sour cherry cultivars. *Journal of Food Composition and Analysis, 24*(6), 772–776. https://doi.org/10.1016/j.jfca.2011.03.004

Khoo, G. M., Clausen, M. R., Pedersen, B. H., & Larsen, E. (2012). Bioactivity of sour cherry cultivars grown in Denmark. *Phytotherapy Research, 26*(9), 1348–1351. https://doi.org/10.1002/ptr.3726

Khoo, H. E., Azlan, A., Tang, S. T., & Lim, S. M. (2017). Anthocyanidins and anthocyanins: Colored pigments as food, pharmaceutical ingredients, and the potential health benefits. *Food & Nutrition Research, 61*(1), 1361779. https://doi.org/10.1080/16546628.2017.1361779

Kim, D. -O., & Padilla-Zakour, O. I. (2004). Jam Processing Effect on Phenolics and Antioxidant Capacity in Anthocyanin-rich Fruits: Cherry, Plum, and Raspberry. *Journal of Food Science*, *69*(9). https://doi.org/10.1111/j.1365-2621.2004.tb09956.x

Kim, D.-O., Heo, H. J., Kim, Y. J., Yang, H. S., & Lee, C. Y. (2005). Sweet and sour cherry phenolics and their protective effects on neuronal cells. *Journal of Agricultural and Food Chemistry, 53*(26), 9921–9927. https://doi.org/10.1021/jf0518599

Kim, D.-W., Jung, D.-H., Sung, J., Min, I. S., & Lee, S.-J. (2021). Tart cherry extract containing chlorogenic acid, quercetin, and kaempferol inhibits the mitochondrial apoptotic cell death elicited by airborne PM10 in human epidermal keratinocytes. *Antioxidants, 10*(3), 443. https://doi.org/10.3390/antiox10030443

Kimble, R., Keane, K. M., Lodge, J. K., & Howatson, G. (2021). The influence of tart cherry (*Prunus cerasus*, cv Montmorency) concentrate supplementation for 3 months on cardiometabolic risk factors in middle-aged adults: A randomised, placebo-controlled trial. *Nutrients, 13*(5), 1417. https://doi.org/10.3390/nu13051417

Kirakosyan, A., Seymour, E. M., Wolforth, J., McNish, R., Kaufman, P. B., & Bolling, S. F. (2015). Tissue bioavailability of anthocyanins from whole tart cherry in healthy rats. *Food Chemistry, 171*, 26–31. https://doi.org/10.1016/j.foodchem.2014.08.114

Koca, I., & Ustun, N. S. (2009). Colour stability in sour cherry jam during storage. *Asian Journal of Chemistry, 21*(2), 1011–1016.

Kocabas, S., & Sanlier, N. (2024). The power of berries against cardiovascular diseases. *Nutrition Reviews, 82*(7), 963–977. https://doi.org/10.1093/nutrit/nuad111

Kongthitilerd, P., Thilavech, T., Marnpae, M., Rong, W., Yao, S., Adisakwattana, S., Cheng, H., & Suantawee, T. (2022). Cyanidin-3-rutinoside stimulated insulin secretion through activation of L-type voltage-dependent Ca2+ channels and the PLC-IP3 pathway in pancreatic β-cells. *Biomedicine & Pharmacotherapy, 146*, 112494. https://doi.org/10.1016/j.biopha.2021.112494

Kwon, S.-H., Lee, H.-K., Kim, J.-A., Hong, S.-I., Kim, H.-C., Jo, T.-H., Park, Y.-I., Lee, C.-K., Kim, Y.-B., Lee, S.-Y., & Jang, C.-G. (2010). Neuroprotective effects of chlorogenic acid on scopolamine-induced amnesia via anti-acetylcholinesterase and anti-oxidative activities in mice. *European Journal of Pharmacology, 649*(1–3), 210–217. https://doi.org/10.1016/j.ejphar.2010.09.001

Lang, Y., Gao, N., Zang, Z., Meng, X., Lin, Y., Yang, S., Yang, Y., Jin, Z., & Li, B. (2024). Classification and antioxidant assays of polyphenols: A review. *Journal of Future Foods, 4*(3), 193–204. https://doi.org/10.1016/j.jfutfo.2023.07.002

Li, W., Chen, H., Xu, B., Wang, Y., Zhang, C., Cao, Y., & Xing, X. (2023). Research progress on classification, sources and functions of dietary polyphenols for prevention and treatment of chronic diseases. *Journal of Future Foods, 3*(4), 289–305. https://doi.org/10.1016/j.jfutfo.2023.03.001

Li, X., Shi, Z., Zhu, Y., Shen, T., Wang, H., Shui, G., Loor, J. J., Fang, Z., Chen, M., Wang, X., Peng, Z., Song, Y., Wang, Z., Du, X., & Liu, G. (2020). Cyanidin-3-*O*-glucoside improves non-alcoholic fatty liver disease by promoting PINK1-mediated mitophagy in mice. *British Journal of Pharmacology, 177*(15), 3591–3607. https://doi.org/10.1111/bph.15083

Li, Y., Yu, X., Deng, L., Zhou, S., Wang, Y., Zheng, X., & Chu, Q. (2021a). Neochlorogenic acid anchors MCU-based calcium overload for cancer therapy. *Food & Function, 12*(22), 11387–11398. https://doi.org/10.1039/d1fo01393a

Li, Y., Yu, X., Wang, Y., Zheng, X., & Chu, Q. (2021b). Kaempferol-3-O-rutinoside, a flavone derived from *Tetrastigma hemsleyanum*, suppresses lung adenocarcinoma via the calcium signaling pathway. *Food & Function, 12*(18), 8351–8365. https://doi.org/10.1039/d1fo00581b

Liu, H., Huang, Y., Yang, J., Xu, X., Dai, Q., Zhang, Y., Zhao, L., Zhang, M., Zhang, J., Liu, T., & Zhong, L. (2023). Involvement of estrogen receptor activation in kaempferol-3-o-glucoside's protection against aging-related cognition impairment and microglial inflammation. *Experimental Cell Research, 433*(2), 113849. https://doi.org/10.1016/j.yexcr.2023.113849

Liu, H., Xu, Q., Wufuer, H., Li, Z., Sun, R., Jiang, Z., Dou, X., Fu, Q., Campisi, J., & Sun, Y. (2024). Rutin is a potent senomorphic agent to target senescent cells and can improve chemotherapeutic efficacy. *Aging Cell, 23*(1), e13921. https://doi.org/10.1111/acel.13921

Loizzo, M. R., & Tundis, R. (2019). Plant antioxidant for application in food and nutraceutical industries. *Antioxidants, 8*(10), 10. https://doi.org/10.3390/antiox8100453

Lugasi, A., & Takács, M. (2002). Flavonoid aglycons in foods of plant origin II. Fresh and dried fruits. *Acta Alimentaria, 31*(1), 63–71. https://doi.org/10.1556/AAlim.31.2002.1.7

Luo, X., Gong, Y., Jiang, Q., Wang, Q., Li, S., & Liu, L. (2024). Isoquercitrin promotes ferroptosis and oxidative stress in nasopharyngeal carcinoma via the AMPK/NF-κB pathway. *Journal of Biochemical and Molecular Toxicology, 38*(1), e23542. https://doi.org/10.1002/jbt.23542

Mattioli, R., Francioso, A., Mosca, L., & Silva, P. (2020a). Anthocyanins: A comprehensive review of their chemical properties and health effects on cardiovascular and neurodegenerative diseases. *Molecules, 25*(17), 3809. https://doi.org/10.3390/molecules25173809

Mattioli, R., Francioso, A., Mosca, L., & Silva, P. (2020b). Anthocyanins: A comprehensive review of their chemical properties and health effects on cardiovascular and neurodegenerative diseases. *Molecules, 25*(17), 3809. https://doi.org/10.3390/molecules25173809

Milić, A., Daničić, T., Tepić Horecki, A., Šumić, Z., Bursać Kovačević, D., Putnik, P., & Pavlić, B. (2021). Maximizing contents of phytochemicals obtained from dried sour cherries by ultrasound-assisted extraction. *Separations, 8*(9), 155. https://doi.org/10.3390/separations8090155

Mitić, M., V., O., Kostic, D., Micić, R., & Pecev, E. (2012). Polyphenol content and antioxidant activity of sour cherries from Serbia. *Chemical Industry and Chemical Engineering Quarterly*, *18*, 53–62. https://doi.org/10.2298/CICEQ110701046M

Mubarak, A., Bondonno, C. P., Liu, A. H., Considine, M. J., Rich, L., Mas, E., Croft, K. D., & Hodgson, J. M. (2012). Acute effects of chlorogenic acid on nitric oxide status, endothelial function, and blood pressure in healthy volunteers: A randomized trial. *Journal of Agricultural and Food Chemistry, 60*(36), 9130–9136. https://doi.org/10.1021/jf303440j

Mustafa, S. K., Oyouni, A. A. W. A., Aljohani, M. M. H., & Ahmad, M. A. (2020). Polyphenols more than an antioxidant: Role and scope. *Journal of Pure and Applied Microbiology, 14*(1), 47–61. https://doi.org/10.22207/JPAM.14.1.08

Nagy Á. (2016). *Kajszigyümölcsök (Prunus armeniaca L.) polifenol készletének átfogó tömegspektrometriás feltérképezésére* [Phd, Szent István Egyetem (2000–2020)]. https://doi.org/10.14751/SZIE.2016.039

Nagy-Gasztonyi, M., Sass-Kiss, Á., Tömösközi-Farkas, R., Bánáti, D., & Daood, H. G. (2010). Liquid chromatographic analysis of phenolic compounds in organically and conventionally grown varieties of sour cherries. *Chromatographia, 71*(S1), 99–102. https://doi.org/10.1365/s10337-010-1590-1

Narra, F., Piragine, E., Benedetti, G., Ceccanti, C., Florio, M., Spezzini, J., Troisi, F., Giovannoni, R., Martelli, A., & Guidi, L. (2024). Impact of thermal processing on polyphenols, carotenoids, glucosinolates, and ascorbic acid in fruit and vegetables and their cardiovascular benefits. *Comprehensive Reviews in Food Science and Food Safety, 23*(6), e13426. https://doi.org/10.1111/1541-4337.13426

Nemes, A., Szőllősi, E., Stündl, L., Biró, A., Homoki, J. R., Szarvas, M. M., Balogh, P., Cziáky, Z., & Remenyik, J. (2018). Determination of flavonoid and proanthocyanidin profile of Hungarian sour cherry. *Molecules, 23*(12), 3278. https://doi.org/10.3390/molecules23123278

Nowicka, P., & Wojdyło, A. (2016). Stability of phenolic compounds, antioxidant activity and colour through natural sweeteners addition during storage of sour cherry puree. *Food Chemistry, 196*, 925–934. https://doi.org/10.1016/j.foodchem.2015.10.019

Nowicka, P., Wojdyło, A., Lech, K., & Figiel, A. (2015). Influence of osmodehydration pretreatment and combined drying method on the bioactive potential of sour cherry fruits. *Food and Bioprocess Technology, 8*(4), 824–836. https://doi.org/10.1007/s11947-014-1447-y

Park, S. Y., Jin, M. L., Yi, E. H., Kim, Y., & Park, G. (2018). Neochlorogenic acid inhibits against LPS-activated inflammatory responses through up-regulation of Nrf2/HO-1 and involving AMPK pathway. *Environmental Toxicology and Pharmacology, 62*, 1–10. https://doi.org/10.1016/j.etap.2018.06.001

Picariello, G., Ferranti, P., De Cunzo, F., Sacco, E., & Volpe, M. G. (2017). Polyphenol patterns to trace sweet (*Prunus avium*) and tart (*Prunus cerasus*) varieties in cherry jam. *Journal of Food Science and Technology, 54*(8), 2316–2323. https://doi.org/10.1007/s13197-017-2670-0

Poiana, M.-A., Moigradean, D., Dogaru, D., Mateescu, C., Raba, D., & Gergen, I. (2011). Processing and storage impact on the antioxidant properties and color quality of some low sugar fruit jams. *Romanian Biotechnological Letters*, *16*(5), 6504–6512.

Prabhu, S., Molath, A., Choksi, H., Kumar, S., & Mehra, R. (2021). Classifications of polyphenols and their potential application in human health and diseases. *International Journal of Physiology, Nutrition and Physical Education, 6*(1), 293–301. https://doi.org/10.22271/journalofsport.2021.v6.i1e.2236

Proietti, S., Moscatello, S., Villani, F., Mecucci, F., Walker, R. P., Famiani, F., & Battistelli, A. (2019). Quality and nutritional compounds of *Prunus cerasus* L. var. austera fruit grown in central Italy. *HortScience, 54*(6), 1005–1012. https://doi.org/10.21273/HORTSCI13960-19

Rahman, S., Mathew, S., Nair, P., Ramadan, W. S., & Vazhappilly, C. G. (2021). Health benefits of cyanidin-3-glucoside as a potent modulator of Nrf2-mediated oxidative stress. *Inflammopharmacology, 29*(4), 907–923. https://doi.org/10.1007/s10787-021-00799-7

Repajić, M., Kovačević, B. D., Putnik, P., Dragović-Uzelac, V., Kušt, J., Levaj, B. and C. (2015). Influences of Cultivars and Industrial Processing on Polyphenols in Sour Cherry (Prunus cerasus L.) Concentrated Juices. *Food Technology and Biotechnology*, *53*. https://doi.org/10.17113/ftb.53.02.15.4151

Sabou, V. R., O'Leary, M. F., Liu, Y., Brown, P. N., Murch, S., & Bowtell, J. L. (2021). Review of Analytical Methods and Reporting of the Polyphenol Content of Tart Cherry Supplements in Human Supplementation Studies Investigating Health and Exercise Performance Effects: Recommendations for Good Practice. *Frontiers in Nutrition, 8*, 652094. https://doi.org/10.3389/fnut.2021.652094

Schlesinger, N., Lipsky, P. E., Jablonski, K., Jarjour, W., Brunetti, L., & Young, N. A. (2022). Components of tart cherry juice inhibit NFκB activation and inflammation in acute gout. *Clinical and Experimental Rheumatology*, *40*(7), 1293–1298. https://doi.org/10.55563/clinexprheumatol/xnb7hp

Serradilla, M. J., Hernández, A., López-Corrales, M., Ruiz-Moyano, S., de Guía Córdoba, M., & Martín, A. (2016). Composition of the Cherry (*Prunus avium* L. and *Prunus cerasus* L.; Rosaceae). In M. S. J. Simmonds & V. R. Preedy (Szerk.), *Nutritional Composition of Fruit Cultivars* (o. 127–147). Academic Press. https://doi.org/10.1016/B978-0-12-408117-8.00006-4

Sharma, A., Shahzad, B., Rehman, A., Bhardwaj, R., Landi, M., & Zheng, B. (2019). Response of phenylpropanoid pathway and the role of polyphenols in plants under abiotic stress. *Molecules, 24*(13), 2452. https://doi.org/10.3390/molecules24132452

Sokół-Łętowska, A., Kucharska, A. Z., Hodun, G., & Gołba, M. (2020). Chemical composition of 21 cultivars of sour cherry (*Prunus cerasus*) fruit cultivated in Poland. *Molecules, 25*(19), 4587. https://doi.org/10.3390/molecules25194587

Sokół-Łętowska, A., Kucharska, A. Z., Szumny, A., Wińska, K., & Nawirska-Olszańska, A. (2018). Phenolic composition stability and antioxidant activity of sour cherry liqueurs. *Molecules, 23*(9), 2156. https://doi.org/10.3390/molecules23092156

Sokół-Łętowska, A., Kucharska, A. Z., Wińska, K., Szumny, A., Nawirska-Olszańska, A., Mizgier, P., & Wyspiańska, D. (2014). Composition and antioxidant activity of red fruit liqueurs. *Food Chemistry, 157*, 533–539. https://doi.org/10.1016/j.foodchem.2014.02.083

Song, L., Wu, T., Zhang, L., Wan, J., & Ruan, Z. (2022). Chlorogenic acid improves the intestinal barrier by relieving endoplasmic reticulum stress and inhibiting ROCK/MLCK signaling pathways. *Food & Function, 13*(8), 4562–4575. https://doi.org/10.1039/D1FO02662C

Szalóki-Dorkó, L., Végvári, G. (2015). Degradation of Anthocyanin Content in Sour Cherry Juice During Heat Treatment. *Food Technology and Biotechnology*, *53*. (3) 354–360. https://doi.org/10.17113/ftb.53.03.15.3931

Tenuta, M. C., Artoni, E., Fava, P., Bignami, C., & Licciardello, F. (2023). Shelf life extension and nutritional quality preservation of sour cherries through high pressure processing. *Foods, 12*(2), 342. https://doi.org/10.3390/foods12020342

Thilavech, T., & Adisakwattana, S. (2019). Cyanidin-3-rutinoside acts as a natural inhibitor of intestinal lipid digestion and absorption. *BMC Complementary and Alternative Medicine, 19*(1), 242. https://doi.org/10.1186/s12906-019-2664-8

Thilavech, T., Abeywardena, M. Y., Adams, M., Dallimore, J., & Adisakwattana, S. (2017). Naturally occurring anthocyanin cyanidin-3-rutinoside possesses inherent vasorelaxant actions and prevents methylglyoxal-induced vascular dysfunction in rat aorta and mesenteric arterial bed. *Biomedicine & Pharmacotherapy, 95*, 1251–1259. https://doi.org/10.1016/j.biopha.2017.09.053

Topa, E., Alexa, L., Varga-Kántor, A., Kovács, B., & Czipa, N. (2021). Quality characteristics of red fruits fresh and after lyophilization. *Élelmiszervizsgálati Közlemények, 67*(4), 3657–3664. https://doi.org/10.52091/EVIK-2021/4-2-ENG

Toydemir, G., Capanoglu, E., Kamiloglu, S., Boyacioglu, D., De Vos, R. C. H., Hall, R. D., & Beekwilder, J. (2013). Changes in sour cherry (*Prunus cerasus* L.) antioxidants during nectar processing and in vitro gastrointestinal digestion. *Journal of Functional Foods, 5*(3), 1402–1413. https://doi.org/10.1016/j.jff.2013.05.008

Verma, S., Dutta, A., Dahiya, A., & Kalra, N. (2022). Quercetin-3-rutinoside alleviates radiation-induced lung inflammation and fibrosis via regulation of NF-κB/TGF-β1 signaling. *Phytomedicine, 99*, 154004. https://doi.org/10.1016/j.phymed.2022.154004

Viljevac Vuletić, M., Dugalić, K., Mihaljević, I., Tomaš, V., Vuković, D., Zdunić, Z., Puškar, B., & Jurković, Z. (2017). Season, location and cultivar influence on bioactive compounds of sour cherry fruits. *Plant, Soil and Environment, 63*(9), 389–395. https://doi.org/10.17221/472/2017-PSE

Vukoja, J., Pichler, A., & Kopjar, M. (2019). Stability of anthocyanins, phenolics and color of tart cherry jams. *Foods, 8*(7), 255. https://doi.org/10.3390/foods8070255

Wallace, T. C., & Giusti, M. M. (2019). Anthocyanins—nature's bold, beautiful, and health-promoting colors. *Foods, 8*(11), 11. https://doi.org/10.3390/foods8110550

Wang, L., Ma, J., Chen, C., Lin, B., Xie, S., Yang, W., Qian, J., & Zhang, Y. (2024). Isoquercitrin alleviates pirarubicin-induced cardiotoxicity in vivo and in vitro by inhibiting apoptosis through Phlpp1/AKT/Bcl-2 signaling pathway. *Frontiers in Pharmacology, 15*, 1315001. https://doi.org/10.3389/fphar.2024.1315001

Wang, Y., Huo, Y., Zhao, L., Lu, F., Wang, O., Yang, X., Ji, B., & Zhou, F. (2016). Cyanidin-3-glucoside and its phenolic acid metabolites attenuate visible light-induced retinal degeneration in vivo via activation of Nrf2/HO-1 pathway and NF-κB suppression. *Molecular Nutrition & Food Research, 60*(7), 1564–1577. https://doi.org/10.1002/mnfr.201501048

Yang, D., Ran, Y., Li, X., Jiang, X., Chen, J., Sun, J., Tian, L., Teerds, K., & Bai, W. (2022a). Cyanidin-3-O-glucoside ameliorates cadmium induced uterine epithelium proliferation in mice. *Journal of Hazardous Materials, 425*, 127571. https://doi.org/10.1016/j.jhazmat.2021.127571

Yang, T.-Y., Wu, Y.-L., Yu, M.-H., Hung, T.-W., Chan, K.-C., & Wang, C.-J. (2022b). Mulberry Leaf and Neochlorogenic Acid Alleviates Glucolipotoxicity-Induced Oxidative Stress and Inhibits Proliferation/Migration via Downregulating Ras and FAK Signaling Pathway in Vascular Smooth Muscle Cell. *Nutrients, 14*(15), 3006. https://doi.org/10.3390/nu14153006

Yarmolinsky, L., Budovsky, A., Khalfin, B., Yarmolinsky, L., & Ben-Shabat, S. (2022). Medicinal properties of *Anchusa strigosa* and its active compounds. *Molecules, 27*(23), 8239. https://doi.org/10.3390/molecules27238239

Yıldız, D., Gürel, D. B., Çağındı, Ö., & Kayaardı, S. (2022). Heat treatment and microwave applications on homemade sour cherry juice: The effect on anthocyanin content and some physicochemical properties. *Current Plant Biology, 29*, 100242. https://doi.org/10.1016/j.cpb.2022.100242

Yu, H.-R., & Chen, B.-H. (2023). Analysis of phenolic acids and flavonoids in rabbiteye blueberry leaves by UPLC-MS/MS and preparation of nanoemulsions and extracts for improving antiaging effects in mice. *Foods, 12*(10), 1942. https://doi.org/10.3390/foods12101942

Yu, M.-H., Hung, T.-W., Wang, C.-C., Wu, S.-W., Yang, T.-W., Yang, C.-Y., Tseng, T.-H., & Wang, C.-J. (2021). Neochlorogenic acid attenuates hepatic lipid accumulation and inflammation via regulating miR-34a in vitro. *International Journal of Molecular Sciences, 22*(23), 13163. https://doi.org/10.3390/ijms222313163

Zheng, W., Wang, H., Wang, X., Li, X., Hu, J., Zi, X., Zhou, Y., Pan, D., & Fu, Y. (2024). Kaempferol 3-O-rutinoside, a flavone derived from *Tetrastigma hemsleyanum* Diels et Gilg, reduces body temperature through accelerating the elimination of IL-6 and TNF-α in a mouse fever model. *Molecules, 29*(7), 7. https://doi.org/10.3390/molecules29071641

Zhong, S., Yang, Y.-N., Huo, J.-X., Sun, Y.-Q., Zhao, H., Dong, X.-T., Feng, J.-Y., Zhao, J., Wu, C.-M., & Li, Y.-G. (2025). Cyanidin-3-rutinoside from *Mori Fructus* ameliorates dyslipidemia via modulating gut microbiota and lipid metabolism pathway. *The Journal of Nutritional Biochemistry, 137*, 109834. https://doi.org/10.1016/j.jnutbio.2024.109834

Zorić, Z., Pedisić, S., Kovačević, D. B., Ježek, D., & Dragović-Uzelac, V. (2016). Impact of packaging material and storage conditions on polyphenol stability, colour and sensory characteristics of freeze-dried sour cherry (*prunus cerasus* var. Marasca). *Journal of Food Science and Technology, 53*(2), 1247–1258. https://doi.org/10.1007/s13197-015-2097-4

Zorić, Z., Pelaić, Z., Pedisić, S., Elez Garofulić, I., Bursać Kovačević, D., & Dragović-Uzelac, V. (2017). Effect of storage conditions on phenolic content and antioxidant capacity of spray dried sour cherry powder. *LWT - Food Science and Technology, 79*, 251–259. https://doi.org/10.1016/j.lwt.2017.01.049

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