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REVIEW ARTICLE

Functional properties of Cornelian cherry (*Cornus mas* L.): a comprehensive review

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Abstract
Cornus mas, also known as the Cornelian cherry, is a plant that grows in Eastern Europe and the Middle East. Its green leaves and reddish oval fruits are associated with many beneficial properties such as antioxidative and anti-inflammatory effects. These features are driven by the rich polyphenolic composition, with anthocyanins and iridoids in Cornelian cherry fruits as well as flavonoids and phenolic acids in leaves. The antioxidant behavior as well as the composition significantly depends on the cultivar of the plant and its genotype. The functional properties of Cornelian cherry have been recognized in many in vitro and toxicological studies. *Cornus mas* fruits and their extracts have been found to have significant antiatherogenic, anti-inflammatory, and neuroprotective effects. The beneficial effect of *C. mas* fruits as a food component has been determined in numerous papers focused on functional food. However, there is no information in existing literature about *C. mas* leaves in functional food applications. This paper presents the results of current studies including their synthesis to answer the question whether the Cornelian cherry exhibits positive properties due to its bioactive compound content.

Keywords *Cornus mas* · Polyphenols · Anthocyanins · Antioxidative activity · Functional foods

Introduction

The Cornelian cherry, also known as dogwood, is a plant that grows in the east and south regions of Europe and in West Asia. Cornelian cherry trees reach 7–8 m in height and can grow in temperate climate on drained soils [1, 2]. Fruits are edible with an oval or pear-like shape and ranging in color from red to purple. The weight of the Cornelian cherry's fruit ranges from 2.09 to 9.17 g, depending on the plant genotype and cultivation conditions [3, 4]. Fruit harvest yields 500–1000 kg per hectare in the case of wild-growing plants, but in orchards the yield can increase even fivefold [5]. Klimenko states that one wild-growing bush of Cornelian cherry can yield 2.8–10 kg of fruit, whereas yield reaches 80 kg per bush for trees cultivated in an orchard [6]. The fruits are usually harvested when their peel color becomes very intense and the flavor develops to an acceptable limit [7]. *Cornus mas* is famous for being a rich source of vitamin C and polyphenols. Significant amounts of flavonoids, anthocyanins, and iridoids were identified in the fruits and leaves of the Cornelian cherry. These compounds are linked with intense radical scavenging potential and antitumour properties [8, 9]. *Cornus mas* is also a traditional component of liquors, jams, comfitures and other fruit-based products [2]. Cornelian cherry has many regional cultivars which differ between each other in physical properties (i.e., shape, fruit color, etc.) as well as nutrient composition [10]. The Cornelian cherry is a recognized food ingredient in traditional cuisines of Poland, Czech Republic, Serbia, Romania, Turkey, and Iran [1, 2, 11–14]. In Poland and Ukraine, the tradition of growing and using the Cornelian cherry in cuisine was interrupted by post-World War II social and cultural changes which were a result of habitat erosion [6, 15].

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The phytochemicals present in *Cornus mas* L. have anti-inflammatory and antiatherosclerotic properties in vivo; they can also protect cells against the neurogeneration process [16–18].

Recently, research into the potential application of *Cornus mas* has been conducted and expanded by numerous examples of novel functional food applications based on the Cornelian cherry's fruits extracts. Foods including extracts from the Cornelian cherry featured a higher antioxidative potential than their its standard equivalents; they were also accepted by consumers [19, 20].

The aim of this paper is to present recent information about the Cornelian cherry's nutrients, pro-health properties, and examples of its usage in functional food production.

Sugar and mineral salt composition in *Cornus mas* L. fruits

Cornelian cherry's fruit is rich in microelements such as copper, zinc, and manganese. Concentration values for these minerals in fresh fruit are estimated at 110–170, 260–350 and 2400–2900 µg/100 g, respectively [21]. The Cornelian cherry is also a valuable source of potassium—it contains over 3500 mg/100 g of fresh fruit, which means that 1 g of *Cornus mas* meets the full intake of potassium recommended by the WHO [21, 22]. Similar results were provided by Gozlekci et al., noting that the potassium concentration in Cornelian cherry was cultivar deviated and the concentration value ranged 2780–3340 mg per 100 g fw (fresh weight) [23]. Juice made from the Cornelian cherry was rich in calcium (32.3 mg/100 ml) and micronutrients such as iron, zinc, and manganese [24].

The water concentration in fresh as well as in frozen *Cornus mas* fruit was three times higher than in dry fruit (327.53% and 314.42%, respectively) [25]. Polatoglu and Bese noted that the moisture content in fresh Cornelian cherry was about 75.4% [26].

The soluble solids content (SSC) ranged from 10.7 to 19.3% which significantly correlated with genotype variation [27]. Ercisli et al. [28] noted that this parameter ranges from 13.7 to 18.6%, which is similar to those found by Vidrih et al. [27]. The SSC depends on the maturity of the fruit. According to Serce et al., SSC for blush cornelian cherries equals 12.2%, while for mature, dark red fruit this value rises to 16.5% [7].

The reducing sugars content (RSC) in fresh fruit juice ranged from 8.64 to 15.24% [29] for five different Turkish genotypes. According to Yilmaz et al., RSC measured for Turkish Cornelian cherry was between 2.81 and 7.06% [3]. Serbian cultivars had similar RSC values (13.58–20.85%), with the highest value represented by the cultivar that ripened the latest [30]. In Polish cultivars, the RSC value was between 9.08 and 14.70%, while the total sugars content (TSC) was equal to 10.23–16.29%. The poorest RSC and TSC values were found in the cv. *Podolski*, while cv. *Szafer* was the richest in sugars [15]. As opposed to the Serbian Cornelian cherries, the Polish equivalents were harvested at the same time, indicating that the significant sugar content variation is not based solely on differences in cultivation. Fructose and glucose were predominant among the reducing sugars (3.69 and 5.39%, respectively) [31].

Dietary fiber composition is also dependent on the cultivar variation. Nawirska-Olszańska et al. observed that neutral dietary fiber and acidic dietary fiber differed between tested cultivars between 10.7–16.1 g/100 g fresh weight (fw) and 7.6–12.2 g/100 g fw, respectively [32]. In the same paper, the authors found that the Polish Cornelian cherry cultivars contained pectins, hemicelluloses, and lignins (contents appr. 1.0–1.6 g/100 g fw, 2.3–4.5 g/100 g, and 3.3–8.5 g/100 g fw, respectively). According to Tarko et al., the total dietary fiber amount in *Cornus mas* (over 1.53%) is significantly lower than the values noted for apples or bananas [31]. The dietary fiber and polysaccharides content is dependent on the growing conditions, as is the case for other phytocompounds [32, 33].

Phytocompounds composition in Cornelian cherry fruits

In the Cornelian cherry, the presence of an abundance of polyphenolic compounds was confirmed. According to De Biaggi et al., the total polyphenol amount reached 37% of all bioactive compounds described in the paper (i.e., polyphenols, monoterpenes, organic acids, and vitamin C) measured in fresh weight of fruits [9]. The usually detected organic molecules in *Cornus mas* can be divided into five structural groups: anthocyanins, iridoids, phenolic acids, flavonoids, and tannins [34]. The total amount of polyphenols ranged from 219.08 to 976.51 mg/100 g of fresh weight, due to differences in the extraction process and cultivars used in research [12, 34, 35]. Rop et al. stated that the total amount of polyphenolic content was cultivar dependent. In their study, the total polyphenolic content was the lowest for the *Devin* cultivar (261 mg gallic acid equivalent (GAE)/100 g fw), and the *Vydubieckii* had the highest concentration of polyphenol (811 mg GAE/100 g fw) [2]. Kucharska et al. presented research following the same method, but their data showed that the richest in polyphenols was cv. *Szafer* (464 mg/100 g) and the poorest was cv. *Juliusz* (262 mg/100 g) [15]. These proceedings are consistent with Yilmaz et al.'s paper, in which they showed how the polyphenol concentration was genetically related [3]. Polyphenol content can be linked to the amount of juice and peel color [30, 36, 37]. Cultivar *Szafer* possessed the most intense purple color of all cultivars, and it was also the richest in TPC among the cultivars tested by Kucharska et al. In the study by Adamenko et al. [38], an analogous relationship could be noticed in meads prepared with different *Cornus mas* juices with different colors ranging from amber yellow to red. Another question addressed by the researchers was the percentage of stone mass in total fruit mass. The bigger the stone mass, the more decreased are the results for TPC expressed in GAE per fresh mass ratio. Milenkovic-Andjelkovic et al. indicated in their study that the polyphenol content slightly depended on the cultivation conditions which differ from year to year (90 mg GAE/g dry weight (dw) in 1 year and 91 mg GAE/g dw in the following one) [4].

The prevalent phytocompounds in fruits are catechins—cyclic organic molecules classified as flavonoids—as well as phenolic acids [9]. In a study performed by De Biagii et al., the four major ingredients were: ellagic acid, epicatechin, catechin and chlorogenic acid (Table 1). The less significant cinnamic acid derivatives were ferulic acid, coumaric acid, caffeic acid and vescalagin (appr. 2, 4, 1 and 5 mg/100 g fw, respectively) [9]. Moldovan et al. proved that the most prevalent components were quercetin-3-O-glucuronide (471 mg/100 g fw), kaempferol-3-O-galactoside (366.88 mg/100 g fw) and ellagic acid (Table 1) [12]. Moreover, their findings concerning polyphenolic acid and catechin composition are inconsistent with research by De Biaggi et al. (Table 1). The variance can be explained by the differences in analytical procedures, concerning the extraction process and HPLC analysis conditions. The effect of environmental factors such as insolation or amount of rainfall on phytochemical content in plant tissues can be significant [39, 40]. According to Pawłowska et al., the total amount of quercetin derivatives in fruits was nearly fourfold higher than in the data published by Molodovan et al. (Table 1). In the study by Pawlowska et al., the quercetin derivatives were identified as quercetin 3-O-xyloside, quercetin 3-O-rhamnoside, quercetin 3-O-rutinoside, quercetin 3-O-galactoside, quercetin 3-O-glucoside and quercetin 3-O-glucuronide, where the last one predominated (nearly 700 mg/100 g) [41]. In Moldovan et al.'s paper, only one quercetin analogue was tested [12].

Anthocyanins are specific compounds with a pro-health impact found in functional foods, and are also included in Cornelian cherry fruits. They are relatively unstable and reactive molecules and its color depends on pH, temperature, light exposure, and metal presence [42]. They play a dual role as natural pigments and bioactive compounds. These pigments are easily degraded in standard food manufacturing conditions as well as during storage, which results in significant changes in their color and nutritional value [43, 44].

Among the anthocyanins present in *Cornus mas*, the prevalent constituents are 3-O-galactosides of delphinidin (162 mg/100 g), cyanidin (166 mg/100 g) and pelargonidin; cyanidin-3-O-galactoside (3.82 mg/100 g fw) as well as pelargonidin 3-O-glucoside (58.62 mg/100 g fw) and 3-O-rutinoside (33.8 mg/100 g fw) (Fig. 1) [12, 34]. Anthocyanins are compounds with antioxidant behavior confirmed in many studies [45–47]. Moreover, anthocyanins can create complexes with DNA strands and therefore protect genetic material against oxidative stress [48]. Unfortunately, the bioavailability of anthocyanins by humans is relatively low [49, 50]. In *Cornus mas*, sakuratenin (a naringenin methylated form) and aromadendrin were also detected [51].

A broader study of anthocyanins present in different *C. mas* cultivars was performed by Kucharska et al. The cultivate *Czarny* possessed the highest amount of anthocyanins among all the tested varieties (341.18 mg/100 g fw), whereas the cv. *Yantarnyi* had no anthocyanins at all [52]. In the same study, the authors concluded that the prevalent compounds were galactosides of pelargonidin and cyanidin. The differences in anthocyanins and organic acid concentrations between the tested cultivars and genotypes were pH related. The pH value of 2 which is natural for Cornelian cherry juice caused a hypochromic effect on its UV–Vis spectra, whereas a decrease of the pH to 4.0 generated the bathochromic effect [53].

Table 1 Catechins and phenolic acids present in *Cornus mas* fruits expressed in mg/100 g fw [9, 12, 41]

References	De Biaggi et al. [9]	Moldovan et al. [12]	Pawlowska et al. [41]
Ellagic acid	23.56 ± 0.67	187.91 ± 5.87	Ne
Epicatechin	21.74 ± 0.99	66.89 ± 2.88	Ne
Catechin	14.38 ± 0.20	37.06 ± 1.73	Ne
Chlorogenic acid	11.27 ± 0.04	32.76 ± 1.24	Ne
Caffeic acid	0.66 ± 0.00	27.12 ± 1.02	Ne
Kaempferol-3-O-galactoside	Ne	366.88 ± 7.82	413
Total amount of quercetin	Nd	471.01 ± 9.15	1679

N = 3

Ne not examined in study, *Nd* not detected

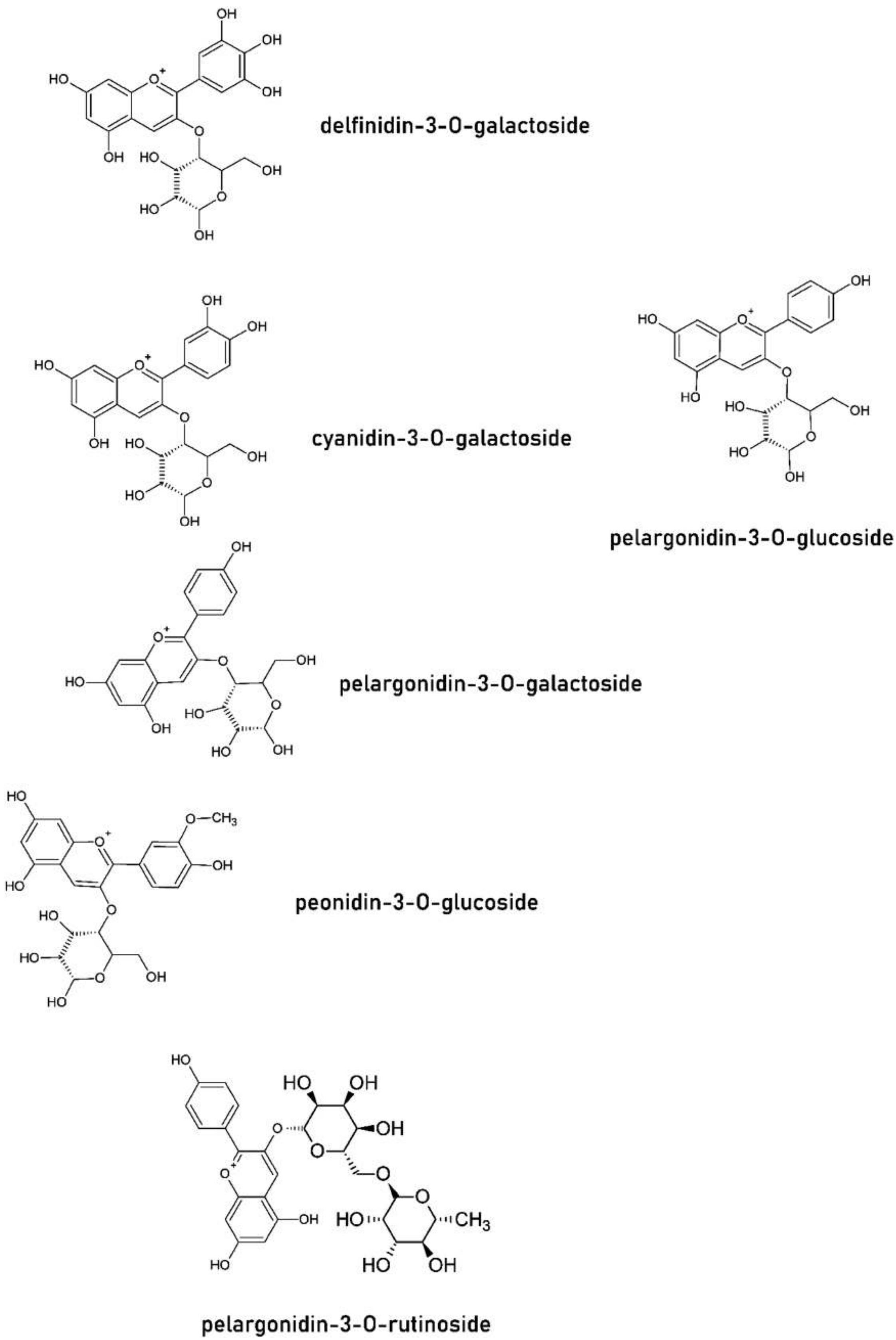

Fig. 1 Chemical structures of anthocyanins present in Cornelian cherry [12, 34]

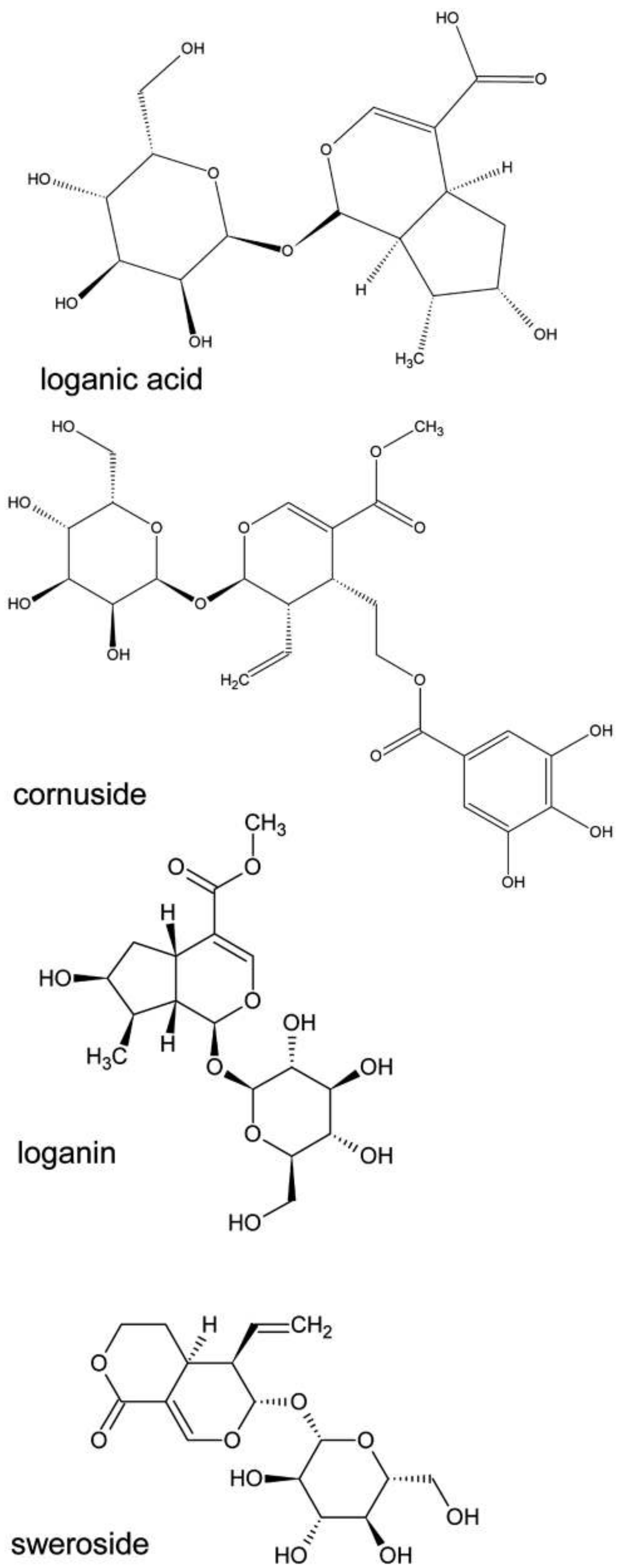

Fig. 2 The chemical structures of loganic acid, loganin, sweroside and cornuside [52, 56]

Besides anthocyanins, the Cornelian cherry also contains iridoids—organic molecules with anti-inflammatory and antioxidative properties [34]. In *Cornus mas*, two iridoids have been detected—cornuside and loganic acid (Fig. 2), and their concentrations in ripe fruits range from 8.22–36.25 mg/100 g fw for the first to 81.53–461.08 mg/100 g fw for the latter, according to cited research [8, 38, 52]. This can be related to the growing conditions and stress factors affecting the plant, including harsh climate and insect attacks [54, 55]. Iridoids are the compounds which protect plants against consumption by insects [55]. An assay performed by Deng et al. demonstrated that loganin and sweroside are also present in Cornelian cherry fruits (Fig. 2). In addition to iridoids, tartaric acid and malic acid at concentrations 1.5–1.6-fold higher than cornuside were detected in Cornelian cherry [56].

The differences in the amounts of iridoids are linked to the analysis method, cultivar used, and cultivation practice [52].

To conclude the works cited in this paragraph, we concur that qualitative characteristics and quantitative content of Cornelian cherry fruits depend on many factors. Authors usually highlight the impact of cultivar, cultivation conditions, plant growth conditions and the extraction process on fruit content. The analytical method is often discussed as well. However, in its entirety, the existing research indicates that polyphenols are the predominant compounds in the Cornelian cherry, mainly composed of phenolic acids (i.e., benzoic acid derivatives and cinnamic acid derivatives) and flavonols, particularly quercetin derivatives.

Ascorbic acid content

Vitamin C as an antioxidant plays a protective role in cardiovascular diseases. Moreover, many studies show that its reactions and conversions help to stimulate biological processes [57]. Ascorbic acid is vital for the proper functioning of the immune system, as it takes part in the immunomodulatory processes and stimulates the interferon synthesis. Vitamin C is a cofactor of numerous enzymes containing ferrous ions, i.e., hydroxylases and oxygenases. The presence of the ascorbic acid is vital for keeping ferrous ions reduced [58].

The concentration of vitamin C in Cornelian cherry has been widely examined [1, 2, 12, 34]. Its concentration ranges from over 29 to nearly 300 mg/100 g fw (Table 2). According to Yilmaz et al., the concentration of ascorbic acid in *Cornus mas* was twofold higher than in oranges [3]. Pantelidis et al. confirmed that and noted that vitamin C content in Cornelian cherry was meaningfully higher than in kiwi and strawberries (29–80 mg/100 mg fw and 31 mg/100 mg fw, respectively) [59].

Table 2 Concentration of ascorbic acid in *Cornus mas* fruits according to cited sources

References	Vidrih et al. [27] HPLC	Kostecka et al. [60] Spectroscopic	Kostecka et al. [60] Iodometric	Pantelidis et al. [59] Reflectometry[a]	Aghdam et al. [61] Spectroscopic	Hassanpour et al. [62] Spectroscopic
Ascorbic acid	29–86	55–83	153–237	103 ± 13	85	183–300

Concentrations given in mg per 100 g fw [27, 59–61]

[a] $N = 3$

The deviation in ascorbic acid concentration can be explained by two independent factors. First, the composition of vitamin C is related to the genotype and cultivar of analyzed Cornelian cherry fruit [27]. In Iranian Cornelian cherry's fruit, the concentration of ascorbic acid ranged between 183 and 300 mg/100 g, whereas for the Czech cultivars grown in the moderate, more humid and colder climate, the ascorbic acid concentration ranged between 175 and 277 mg/100 g [2, 62]. For the varieties grown in Poland, this range varied between 34 and 75 mg/100 g [60]. Second, the method of detection can be the source of the variation. In the research done by Kostecka et al., it was shown how the method affected the ascorbic acid content [60]. For the same genotype of *C. mas*, the results can be threefold higher when the iodometric and spectroscopic methods are compared (Table 2).

The addition of $CaCl_2$ to the fruits after harvesting led to a 1.5-fold or even twofold higher concentration of ascorbic acid in fruit extracts [61]. Similar results were reached after salicylic acid treatment—the rise in vitamin C value was over 30% after 2 mM of salicylic acid treatment [13]. The addition of $CaCl_2$ to tomatoes after harvesting also caused a significant rise in AA level and TSS level [63]. According to Abbasi et al., the higher presence of calcium in fruit flesh, after such a treatment, can inhibit the enzymatic processes in flesh which causes the degradation of vitamin C [63].

Sun drying of the Cornelian cherry fruit is a good way of nonthermal processing of this product, but it causes a drop in vitamin C to over 50%. According to Polatoglu and Bese, this decrease is caused by the light-induced degradation of AA [26]. Similar results were achieved by drying with the use of a food dryer at 60 °C (appr. 45%), as well as by freezing *Cornus mas* fruits (appr. 58%) [25].

As indicated in the paragraphs above, the content of vitamin C depends on various factors, including harvest period, cultivar deviation, cultivation conditions as well as storing and post-harvest treatments. Cornelian cherry as a fruit rich in AA can have beneficial effects related to its presence.

Phytocompounds composition in *Cornus mas* leaves

Cornelian cherry leaves have been recognized as a natural remedy for centuries. Their properties are linked with the plant's secondary metabolites like polyphenols and tannins. In a study performed by Badalica-Petrescu et al., the presence of 15 polyphenolic compounds was confirmed (Fig. 3). The total polyphenol amount was about 105 mg GAE/100 ml of extract which is threefold higher than the total polyphenol concentration in *Crataegus monogyna* evaluated in the same study [14]. According to Forman et al., the total polyphenol concentration in water extract is estimated to be approximately 8.3% [64]. In their second study, Forman et al. noted that the concentration of flavonoids present in *Cornus mas* leaves (0.21%) is lower than for *Cornus kousa*, another edible Cornaceae species [65].

Celep et al. determined that in a 80% (v/v) methanolic extract of Cornelian cherry leaves, the amount of polyphenols reaches 343 mg GAE/g dw and the total flavonoid content equals 73 mg QE (quercetin equivalent)/100 g dw [66]. However, Milenković-Andjleković et al. [4] gained values threefold lower—113–117 mg/100 g dw, which is similar to Badalica-Petrescu et al.'s results. The concentration values for individual compounds are not equal (Table 3). This can be explained by differences in research methodology and variations in the approach to data presentation.

The leaves of *Cornus mas* contain at least 27 organic acids, and the most prevalent are oxalic, palmitic, 2,4-heptadienoic, citric, linoleic and malic acids [67].

Antioxidative effect of Cornelian cherry

The ability of radical scavenging is connected with the rich polyphenolic compounds composition [34]. *Cornus mas* fruit extracts have an antioxidant potential which is poorer than that of other fruits rich in vitamin C. The results depend on the cultivation condition, which was observed by Milenkovic-Andjelkovic et al. In their study, 100 ml of dogwood fruit extract can scavenge 94–109 mg of dissolved DPPH radicals [4].

The DPPH (diphenylpicrylcarbazyl) radical inhibition test is a quick and inexpensive spectrophotometric method of

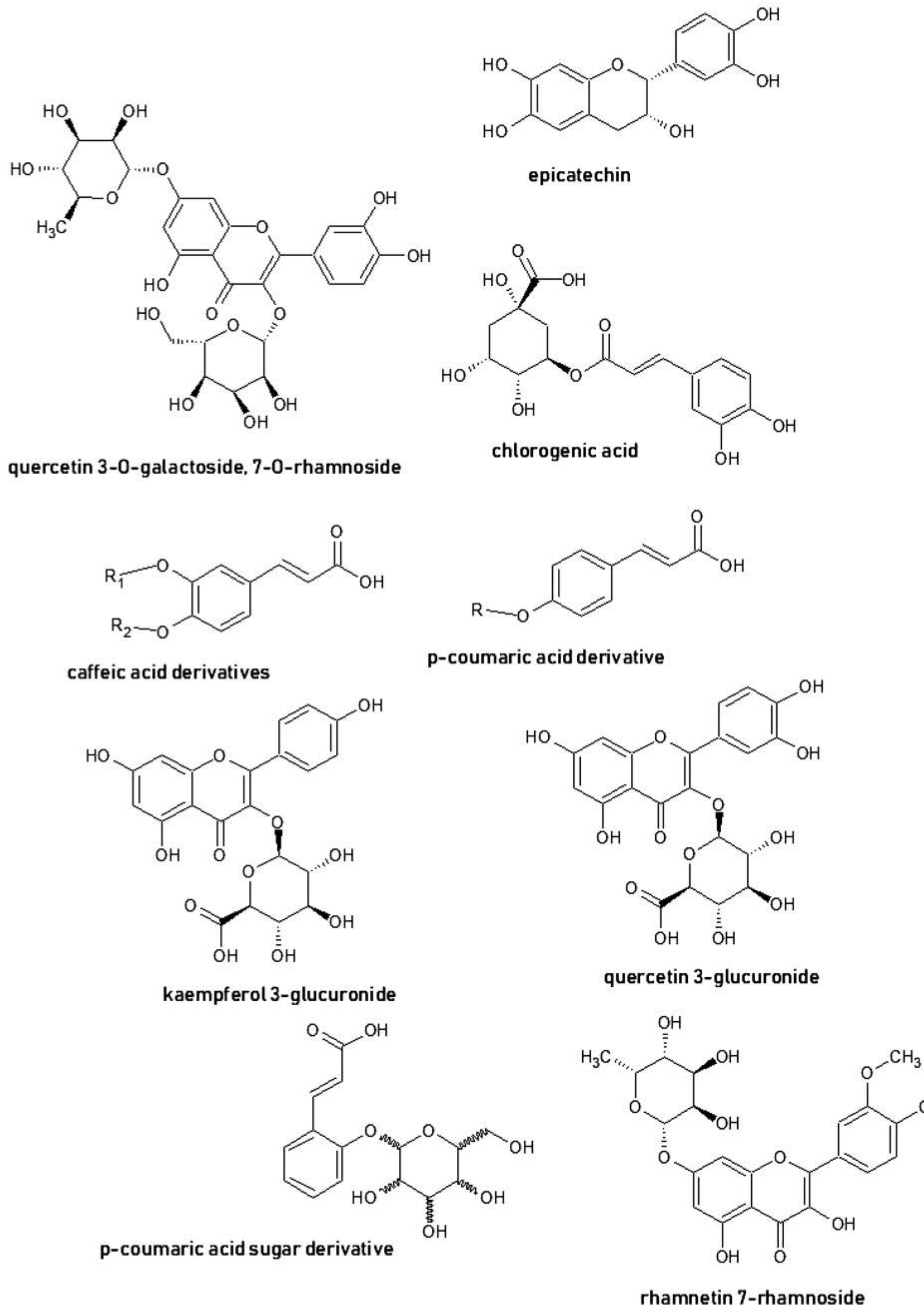

Fig. 3 Polyphenolic compounds detected in *Cornus mas* leaves extracts [14]

Table 3 Phytocompounds present in Cornelian cherry leaves and their concentration values expressed in mg/100 ml. According to cited positions [4, 14]

Compound	Badalica-Petrescu et al. [14] [mg/100 ml]	Milenkovic-Andjelkovic et al. [4] [mg/100 g dw]
Caffeic acid derivatives	6	Ne
Quercetin derivatives	8	928–937
Isorhamnetin-7-rhamnoside	1	Ne
Kaempferol-3-glucuronide	3	Ne
Chlorogenic acid	12	28–33
Epicatechin	14	407–415
Catechin	Ne	222–228
Kaempferol-3-glucoside	Ne	427–437
o-Coumaric acid hexoside	9	Ne
p-Coumaric acid derivative	14	Ne
Vitexin-2′-O-rhamnoside	60	Ne
Vitexin-4′-O-rhamnoside	5	Ne
Rutin	Ne	609–611
Gallic acid	Ne	37–41
Ellagic acid	Ne	255–262

Ne not examined

detection of antioxidative agents in the analyzed samples. The method is based on the addition of samples with antioxidants to a solution of DPPH, afterwards the changes in the absorbance of the DPPH solution are measured.

Hassanpour et al. stated that the efficiency of DPPH radicals' scavenging depends on the total polyphenolic concentration, total flavonoids, and ascorbic acid content (Pearson coefficients: 0.54, 0.60 and 0.47, respectively) [62]. In the cited study, fruit extracts scavenged DPPH radicals at levels varying from 38.98 to 77.6%. The statistical relation between radical scavenging and polyphenolic composition has been additionally proven in many studies [1, 4, 59].

The antioxidative properties are also correlated with the possibility of ferrous ions (Fe^{3+}) reduction. According to Biaggi et al., the Cornelian cherry extract can reduce 20.41 µmol Fe^{2+} per gram of solution [9]. The ferric-reducing antioxidant properties method (FRAP) is regularly treated as a common spectrophotometric assay. The reactive Fe^{3+} ions are reduced by the antioxidative agents to Fe^{2+} at the presence of TPTZ (2,4,6-tripyridyl-s-triazine), which affects the absorbance of the solution at $\lambda = 593$ nm. A study conducted by Yilmaz et al. presents a significant range of FRAP values, in which the minimum is 73 and the maximum reaches 114 µmol AA (ascorbic acid) equivalent per gram of dw [3]. Pantelidis et al. confirms that the FRAP value is approximately 84 µmol AA/g dw [59]. However, Popovic et al. present a different range for this parameter, which is probably caused by a data presence question. In their study, the ferric-reducing antioxidant power ranges from 2 to 65 µmol/ml Fe^{2+} [68].

Studies focusing on Cornelian cherry leaves show that their radical scavenging activity is lower than for fruits. The DPPH radical scavenging capacity ranges between 165 and 790 mg/g (Table 3). Leja et al. stated that radical activity against DPPH equals 94.54%, which is similar to the values for *Rosa canina* (95.08%) and *Crataegus monogyna* (91.70%) described in the same study [35].

Anti-inflammatory effect of Cornelian cherry

Cornelian cherry leaves present significant inhibitory properties against the aldose reductase—an enzyme the overexpression of which is connected with many inflammation processes, cancers as well as diabetes. In an in vivo study, water leaves extract halved the activity of the aldose reductase at a concentration of about 1 µg/ml, which is threefold less than pure quercetin (nearly 3 µg/ml) [69].

In a broader research done by Świerczewska et al., methanolic extracts of Cornelian cherry fruits halved the lipase activity at a concentration of 48 µg/ml, while for the aqueous and ethanolic extracts, this parameter was lower (− 34 and 15 µg/ml, respectively [70]). Furthermore, the intake of powdered *C. mas* by rabbits with an elevated blood cholesterol content led to a significant drop in fibrinogen levels, compared to a drop achieved after a 10 mg lovastatin therapy [71]. Moreover, leaf extracts halved the radionuclei-induced lipid peroxidation ratio [72]. Similar results were obtained for a medical study in which *Cornus mas* extracts seemed to improve the lipid profile and reduce vascular inflammation [73]. In a complex in vivo research, the presence of anthocyanins from Cornelian cherry boosted the expression of PPARγ (193% growth) and PPARα (85.2% growth) in the liver [8]. The peroxisome proliferator-activated receptors (PPAR) are a group of cellular receptors which are responsible for the energy equilibrium, glucose homeostasis, lipid metabolism and oxidation [74]. The PPARγ receptor is responsible for the lipid transformation in cells and is the main regulator of the adipogenesis process [75].

According to Świerczewska et al., Cornelian cherry fruits may reduce the rate of α-amylase activity. From all of the examined extracts, the methanolic one was the most efficient and its IC_{50} value (the concentration which halves the activity rate) reached 79.0 μg/ml [70]. Moreover, a study done by Jayaprakasam et al. proved that the intake of Cornelian cherry inhibits glucose intolerance. According to the authors of this paper, the obesity and sugar intolerance is reduced by anthocyanins, the concentration of which is significant in *C. mas* [76].

The intake of *Cornus mas* by hypercholesterolemic rabbits improved the level of glutathione in their aortas and positively affected their intimae thickness [16]. According to Sozański et al., dimethylarginine species, i.e., asymmetric dimethylarginine and symmetric dimethylarginine (ADMA and SDMA) are known as cardiovascular disorder markers. The authors described that the intake of a lyophilisate of Cornelian cherry fruits resulted in a drop in the dimethylarginine concentration in serum, while the concentration of L-arginine increased, which provided a highly beneficial effect [16]. The protective effect can be also delivered by cornuside itself, as it inhibits the biological synthesis of nitric (NO) radical and tumor necrosis factor alpha (TNF-α), mediated by lipopolysaccharides (LPS) [77, 78]. The authors of the referenced studies tested the impact of *Cornus officinalis*, another species of Cornaceae. However, the biological properties of *Cornus mas* and *C. officinalis* are similar [34] [34].

Cornus mas fruit extracts present a positive anti-parasitological effect. The intake of fruit extracts caused the proliferation of lymphocytes in parasite organisms in vivo [79]. According to Piekarska et al., the results were granted by the beneficial composition of fruit extracts, which are rich in iridoids and anthocyanins. The extracts from both the Cornelian cherry fruits and leaves significantly inhibit the growth of pathogenic bacteria and yeast. In a study performed by Milenkovic-Andjelkovic et al., the presence of leaf extracts inhibits the growth of *Bacillus cereus* and *Clostridium perfringens* in a ratio equal to 2/3 of the tetracycline activity and achieves almost the same activity in *Staphylococcus aureus* growth inhibition [4].

Results provided by Szumny et al. show that Cornelian cherry extracts can help in intraocular pressure decrease, which is linked with a high concentration of iridoids, especially loganic acid, in extracts [80].

Cornelian cherry features neuroprotective effects as well. In an in vivo study, the intake of lyophilized Cornelian cherry boosted the catalase activity in rats' brains [18]. Catalase is an enzyme which cleaves the peroxides made during the oxidative stress. Moreover, an addition of the Cornelian cherry was linked to a higher activity of paraoxonase—an enzyme which stops the lipoproteins oxidation process [18]. However, Celep et al. discovered that methanolic extracts from *C. mas* leaves can decrease the activity of catalase and raise the glutathione (GSH) peroxidase activity both in blood and in liver of rats in vitro [66]. When the livers of rats had been previously treated with CCl_4, the intake of leaves extracts caused a rise in the activity of both catalase and GSH peroxidase proportional to the intake value [66]. Alavian et al. noted that intake of Cornelian cherry by rats inhibits the liver peroxidation process and decreases the amount of proteins in serum [81].

Leaf extracts obtained in Savikin et al.'s study featured meaningful anticancer potential. In the mentioned study, leaf extracts decreased the growth rate of HeLa cells [82]. Similar results were reached for fruits studied by Bahman et al. They observed a significant apoptosis of four carcinogenic cells lines (SKOV3, MCF-7, PC-3 and A549) [83]. According to Leskovac et al., leaf extracts possess radioprotective properties, i.e., they help in cell regeneration after radioactive dosage intake [72].

To conclude, literature contains numerous proceedings describing the positive properties of the Cornelian cherry. These properties are relevant to both the leaves and fruits of the Cornelian cherry. It was shown that the biological activity is related to a group of phytocompounds present in the plants' anatomical parts. Phytocompounds present in leaves (i.e., polyphenols, irydoids, anthocyanins) possess positive anti-inflammatory and anti-cancer properties. Cornelian cherry extracts also positively affect the lipid profile of blood in terms of triglycerides and fibrinogen levels, and reduce the predispositions for cardiovascular diseases. The antidiabetic activity and antibacterial effect against Gram-positive microorganisms were demonstrated as well.

Compounds present in fruits (including anthocyanins, iridoids, and polyphenols) affect the energy balance, glucose and lipid metabolism, and participate in the adipogenesis process. *Cornus mas* fruits contain compounds which inhibit the α-amylase activity and reduce dimethylarginine concentration in serum. Fruit extracts can help in reducing intraocular pressure, they act as neuroprotective agents and inhibit the liver peroxidation process. Moreover, they have positive antibacterial, antifungal, and antiparasitic activities.

Functional food products with Cornelian cherry

The flavor of the Cornelian cherry is specific, cherry-like, and considered as sour or sweet and sour, depending on the tasted cultivar or genotype [33, 84]. The shelf life of ripened fruit is rather short. The storage of harvested Cornelian cherry fruits for a month in cool conditions causes a decay of over 70% of the stored fruits [85]. The modified atmosphere packaging (MAP) of *Cornus mas* fruits can prolong the freshness of the product and protect it against decay [85, 86]. The MAP packaging that was based on an increase in the concentration of oxygen and carbon dioxide in the package to 60% and 20%, respectively, led to a significant improvement in the results of visual assessment of stored fruits and inhibited vitamin C degradation and titratable acidity nearly by half [86].

Cornus mas used to be a traditional component of liquors, jams, and fruit preserves. The Cornelian cherry is generally recognized as a main ingredient of the Dereniówka liquor in Poland and Drenja in Balkan countries [87]. Tesevic et al. [87] analyzed the volatile compounds present in Drenja, which are responsible for the fragrance bouquet and discovered that the predominant compounds were 2- and 3-methyl-1-butanol (analyzed together in the study at conc. 207 mg/100 ml) and ethyl acetate (198 mg/100 ml), whereas Tarko et al. [31] observed that Cornelian cherry wine contained isoamyl alcohols (44 mg/100 ml) and isobutanol fraction (14 mg/100 ml). Ethyl acetate concentration was poorer (4 mg/100 ml). Sokół-Łętowska et al. analyzed the compositions of a few versions of Dereniówka, which differed in sugar concentration and storage conditions (Table 4). Their liquors were prepared from fresh fruit mixed with 65% ethanol at a mass ratio of 1:1 and macerated for 21 days at ambient temperature without light access [88]. According to Dragoni et al., alcohol promotes a higher absorption of quercetin in wine [89]. A similar property should be noted for Cornelian cherry liquor. The rich polyphenolic composition and interesting sweet and sour flavor could draw the attention of functional food producers to the Cornelian cherry. Fruit freshness and maturity are important, because the polyphenolic content in raw material and its antioxidant profile determines the observed levels in ready products [38, 85, 88]. Other studies described the properties of meads made with different cultivars of the Cornelian cherry and various fermentation yeasts used [38]. For juice obtained from cv. *Podolski*, the finished product mead had a higher polyphenolic concentration as well as improved antiradical activity than the *Koralovyi* juice (Table 4). These parameters

Table 4 The reference data on the total polyphenol amount and radical scavenging activities for the model food samples enriched with *Cornus mas* fruits [11, 20, 38, 88, 96–99]

Product	Total polyphenol amount [mg GAE/100 g] or [mg GAE/100 ml]	DPPH scavenging activity [µmol TE/g] or [µmol TE/ml]	ABTS scavenging activity [µmol TE/g] or [µmol TE/ml]	References
Mead with cv. *Podolski* juice	77–90	6	6	Adamenko et al. [38]
Mead with cv. *Koralovyi* juice	42–61	5	6–7	
Jam 50%, conc.	1	2	4	Nawirska et al. [20]
Jam 30% conc.	2	2	4	
Liquor sweetened	25	Nd	Ne	Sokół-Łętowska et al. [88]
Liquor unsweetened	26	Nd	Ne	
Yogurt	72	217	Ne	Barat and Ozcan [96]
'False olives' cv. *Jurek*	87–141	10-13	11–16	Kucharska et al. [11]
'False olives' cv. *Juliusz*	91–133	10–13	12–15	
'False olives'	143–316	12–22	15–32	Czyżowska et al. [97]
Dessert w/*Cornus mas* juice	4	137	Ne	Ivanova et al. [98]
Dessert w/*Cornus mas* juice encapsulated	5	358	Ne	
Cornelian cherry pulp	365	27	Ne	Kucharska et al. [99]
Cornelian cherry pulp with chokeberry 20% conc.	767	47	Ne	

Nd not detected, *Ne* not examined in study, *TE* trolox equivalent were significantly higher than for mead aged without Cornelian cherry (i.e., total polyphenol number appr. 2 mg GAE/100 ml) [38].

In Nawirska et al.'s study, Cornelian cherry was used as an ingredient of jam [20]. The Cornelian cherry concentration differed between two samples, which resulted in different polyphenolic concentrations and antioxidant properties (Table 4). At the preparation stage of functional food production, polyphenols present in raw plants can be removed by elution from plant tissues into an aqueous medium [90, 91]. The thermal treatment of fruits and vegetables can increase free polyphenol concentrations due to the breakdown of plant cells, in which the polyphenols are present [92]. On the other hand, strong interactions between polyphenolic compounds and the cell wall limits limit their extraction, which is positive in terms of the discussed processing losses. During food manufacture and storage, plant polyphenols are converted into various derivatives, mainly due to their sensitivity to heat and the physicochemical environment [90, 91]. These conversions can have an impact on their final antioxidative properties [91]. Additionally, the sugar presence in jam positively affects the flavonoid content in jam after prolonged storage [93]. Results show that the preparation of food rich in anthocyanins causes significant losses of monomeric anthocyanins and a drop in their antioxidant capacity. Anthocyanins are subject to degradation in storage in all thermally treated products—losses may reach up to 40% [94]. Anthocyanins present in *Cornus mas* may be subject to conversions during processes required to prepare functional foods. Physical processes affecting the stability of anthocyanins include washing operations, blanching, canning, and cooking [94, 95].

Barat and Ozcan used Cornelian cherry juice as an additive to yogurt. The addition of Cornelian cherry juice resulted in almost zero syneresis in yogurt (1.40 ml/100 ml) as well as the lowest pH value (3.79) from all tested samples in the paper [96]. The presence of juice resulted in a greater total amount of bacteria in yogurt and had a positive effect on their survivability [96]. Czyżowska et al. conducted a similar experiment in which the Cornelian cherry fruits were fermented by lactic fermentation species such as *Lactobacillus lactis*. They stated that after fermentation, Cornelian cherry fruits were enriched in the microflora at an amount higher [4.73–5.86 log colony-forming units (CFU)] than at the inoculation stage (4.00 log CFU) [97]. The polyphenol content and the antiradical potential in yogurt enriched in *Cornus mas* juice seem to be very significant and in contrast to the food products mentioned earlier (Table 4). The root cause can be traced to microflora metabolism, which hydrolyzes the oligo- and monosaccharic residues from the aglycone, which results in a higher absorbance of polyphenols and affects the polyphenolic content in the food matrix [100]. In Czyżowska et al.'s study, the quantitative determination of iridoids in false olives indicated loganic acid (34.76–130.23 mg/100 g) and cornuside (2.15–15.69 mg/100 g) amounts close to that in ripe, fresh fruits [97].

Similar implications can be drawn from Topdas et al.'s study in which they examined how different percentages of Cornelian cherry addition affected the sensory and antioxidant properties, as well as the concentrations of examined polyphenols [19]. Similar to the study by Barat and Ozcan, the addition of Cornelian cherry pulp resulted in a decrease in the pH value, from 6.7 for the control to even 5.3 for the sample with the highest *Cornus mas* additive [19]. Additionally, the fruit pulp concentration was positively related to the total phenolic content, the sample's general accessibility and flavor, although it had a negative effect on the ice cream's sweetness [19]. If the encapsulation of juice was engaged, the total amount of polyphenols and antioxidant properties soared, probably because of the better homogenization of the food matrix (Table 4). Cerit et al. used Cornelian cherry fruits as an ingredient in white chocolate, which resulted in 2.5-fold higher DPPH radical scavenging and ferric-reducing activity in comparison to white chocolate without this ingredient [101]. These observations show that Cornelian cherry fruits can be used as a functional additive to products traditionally considered as 'junk food' and its presence does not diminish consumer acceptability. Unfortunately, this conclusion cannot be applied to products enriched in Cornelian cherry fruits. Salejda et al. state that the low pH value of Cornelian cherry juice (over 2.4 value) negatively affects the protein structure of burgers during preparation and storage [102].

Fermented unripe Cornelian cherries were served in South-East Poland in ancient times [11]. Thanks to their color and taste, they were used instead of olives as apperitives and additives to salads. Recently, the subject of the so-called 'Polish olives' had its revival thanks to the research papers which highlighted their beneficial properties [11, 97]. In a study performed by Kucharska et al., the total polyphenolic content and antioxidant properties of the Cornelian cherry are slightly different due to the cultivars used in the fermentation process (Table 4). However, the values concerning DPPH scavenging are about fivefold higher for both samples than the parameter measured for 'real' olives (2.1–2.7 μM TE/g). For the cationic radical ABTS [2,2′-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid)], this ratio is smaller (*C. mas*:olives: about 3:1), whereas there is no significant difference in the total amount of polyphenols (for olives 72–134 mg/100 g) [11].

The addition of other fruits to the *C. mas* pulp can sometimes result in a positive, synergistic effect. Kucharska et al. tested how the addition of different berries (chokeberry, strawberry, and raspberry) promotes the antioxidant properties and polyphenol concentration in Cornelian cherry fruit pulp [99]. The findings indicate that a 20% addition of chokeberry to the Cornelian cherry pulp doubles the total polyphenol amount and causes a growth of 75% in DPPH radical scavenging activity (Table 4). The addition of Cornelian cherry to pekmez—Turkish fruit-based syrup, resulted in a better sensory profile, smaller viscosity, and higher concentrations of minerals such as potassium, calcium, iron, and zinc [103].

Another interesting application is fruit vinegar production. Kawa-Rygielska et al. manufactured vinegar from three different cultivars of *Cornus mas* and two different fermentation methods, which resulted in different total phenolic values and antioxidant activity [104]. They fermented pressed Cornelian cherry juices using either one-stage spontaneous fermentation at 25 °C, or a two-stage process: initial alcoholic fermentation by *Saccharomyces bayanus* and then spontaneous vinegar fermentation at 25 °C. Similarly to the paper describing the Dereniówka (traditional Cornelian cherry liqueur) [88], the total polyphenolic amount expressed in mg GAE per 100 ml was the highest for the *Podolski* cultivar, the most reddish one [104]. That indicates a correlation between the concentration of polyphenols and fruit juice color, which was also described in similar papers [2, 3, 100, 105]. Regarding the antioxidant scavenging, the results of the cited study were not affected by the variety used for vinegar production, which can be caused by fact the *Yantarnyi* cultivar (characterized by the lowest total amount of polyphenols) may contain other antioxidative compounds not detected in the study.

Unfortunately, in light of this publication, we could not find works describing the usage of Cornelian cherry leaves in model food or as an ingredient in functional food production. Probably, the application of *Cornus mas* leaves has not yet been explored. The addition of plant leaves to bread is a successful method of providing it with functional properties such as decreasing acrylamide levels in the ready product, growth of polyphenol content and antioxidant properties, as well as the improvement of bread texture [106, 107]. Leaves added to beverages can significantly raise the antioxidant potential and affect the rheological properties of ready product [108, 109]. Due to the multidirectional effect of ingredients present in Cornelian cherry, the application of *Cornus mas* leaves as a supplement additive would warrant plenty of positive impacts on the human organism. The generally known goal of supplement intake and functional product production is to improve the health of consumers. Pro-health ingredients of functional food products and supplements can include mineral components (i.e., calcium, iron, magnesium), pro- and prebiotics, fiber, essential unsaturated fatty acids (n-3 and n-6), soy protein, isoflavones (i.e., genistein) and others [110, 111]. Dietary supplements regularly contain preparations of leaves, which are either not normally consumed in the diet, or they are not functional food ingredients [112, 113]. One example of popular leaf-based supplement ingredients are mulberry leaves. White mulberry (*Morus alba*) is famous for its fruits, while its leaves contain phytocompounds with a high antidiabetic effect. DNJ (1,5 dideoxy-1,5-imino-D-sorbitol), an alkaloid present in leaves, inhibits the activity of α-glycosidases [114–116]. Another dietary supplement component which is widely recognized as rich source of bioactive compounds, are *Ginkgo biloba* leaves [117, 118]. Ginkgo leaves contain substances belonging to flavonoid, terpene and proanthocyanidin groups which thanks to their proportions in the leaves provides beneficial health effects [118]. These ingredients help to improve the blood flow in the brain, due to their protective effect against the peroxidation of cerebral lipids. They also reduce the risk of edema [119]. Currently, research is being conducted on other biological ingredients which could improve the memorization process [120, 121]. To conclude, the results presented above demonstrate that the properties of Cornelian cherry compounds and the current trends in the application of plant leaves as ingredients of dietary supplements result in the purposefulness of research into the application of *Cornus mas* leaves in dietary and medicinal practice.

Conclusion

The Cornelian cherry has significant potential for further research. It is characterized by a high content of iridoids and anthocyanins. The high content of these compounds is related to the significant antioxidant potential of both fruit and leaf extracts. The Cornelian cherry extracts were reported to be potential anti-inflammatory agents both in in vitro and in vivo studies, also in situations when the Cornelian cherry was processed to obtain functional food or traditional meals. Application of fruits to functional food production has been repeatedly described.

The application of Cornelian cherry leaves in functional food may be a separately interesting focus of research and development. Leaves also contain many ingredients beneficial for improving and maintaining health. However, the majority of papers in existing literature have been devoted to the Cornelian cherry fruits and their potential of serving as functional food additives. *Cornus mas* leaves and their properties have been solely considered in studies based on model matrices. In existing literature, there are proceedings indicating the possibility of using leaves as raw material to obtain important biologically active compounds. The current state of knowledge about the properties of the Cornelian cherry can be valuable for both food technologists and pharmacists.

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Compliance with ethical standards

Conflict of interest We declare that we have no conflicts of interest.

Compliance with ethics requirements This article does not contain any studies with human participants or animals performed by any of the authors.

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