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Review

The Beneficial Effects of Anthocyanins from Cornelian Cherry (*Cornus mas* L.) Fruits and Their Possible Uses: A Review

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Abstract: Anthocyanins are pigments ubiquitous in plants that are responsible for the red to almost black color, mainly of flowers and fruits. Dark-colored fruits contain the highest amounts of anthocyanins. A potential source of anthocyanins can be cornelian cherry fruit (*Cornus mas* L.) from a long-lived tree growing in temperate climate zones. The aim of this review is to summarize the latest research on cornelian cherry anthocyanins and the possibility of their use in the food, pharmaceutical, and cosmetic industries, without taking into account their use in medicine. The content of anthocyanins in cornelian cherry fruits is high and comparable to fruits considered to be the richest sources of these compounds, so they may be a good source of these natural colorants used in industry. The content of anthocyanins varies due to genetic traits, growing conditions, the ripeness of fruits, and finally, how the fruits are stored and processed. Anthocyanins can be found in various cornelian products, such as juices, jams, powders, and others, so they may be available outside the period of supply of fresh fruit on the market. The lack of experience on the influence of the method of cultivation of cornelian cherries on the anthocyanin content of fruits determines new directions for research.

Keywords: antioxidant properties; cosmetics; drying; freezing; jams; juices; natural colorants; pharmaceuticals; plant pigments; secondary metabolites

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Citation: Szot, I.; Łysiak, G.P.; Sosnowska, B. The Beneficial Effects of Anthocyanins from Cornelian Cherry (*Cornus mas* L.) Fruits and Their Possible Uses: A Review. *Agriculture* **2024**, *14*, 52. https://doi.org/10.3390/agriculture14010052

Academic Editor: Anna Andolfi

Received: 6 November 2023
Revised: 16 December 2023
Accepted: 21 December 2023
Published: 27 December 2023

1. Introduction

One of the most important factors in consumer sensory evaluation of products are their visual distinguishing features, i.e., color and form. Attractive color is usually associated with good quality and freshness and indirectly affects the perception of taste and smell. Synthetic food dyes are used to color food, cosmetics, and pharmaceuticals obtained by chemical modification of their precursors, which may also be naturally occurring compounds. This is a diverse group of azo, triarylmethane, xanthene, quinoline, and indigoid compounds [1]. Only a few are approved for use in food, as toxicological tests of a number of those originally used showed a negative impact on consumer health and the environment [2]. Currently, there is a growing interest in natural dyes isolated and concentrated from plant extracts. Betalains, carotenoids, phycocyanins, and anthocyanins are the main food colorants used in the food industry, which additionally have documented biological effects, especially in the prevention and treatment of chronic diseases such as diabetes, obesity, and cardiovascular diseases [3].

Anthocyanins are a numerous group of plant pigments soluble in water classified as so-called natural, non-nutrient secondary mathabolites [4]. They are ubiquitous in flowers and fruits and account for plant coloration from orange through red to almost black. However, young leaves and shoots are sometimes intensively pigmented by anthocyanins at the initial stage of plant growth since they lack chlorophyll, masking the color of anthocyanins [5]. Anthocyanins mostly accumulate in the epidermis (peel) of fruits, and their content grows as the plant grows and matures. At the cellular level, they occur in vacuoles as granules of different sizes, and cell walls do not contain anthocyanins [6].

In the human body, anthocyanins play a significant role in the regulation of metabolic processes and show multifaceted health-promoting and preventative effects on many diseases, such as atherosclerosis [7], diabetes [8,9], and tumors [10], as well as cardiovascular diseases [11] and eye diseases. They have an anti-inflammatory [12,13], cardioprotective [14], neuroprotective [15], hepatoprotective [16], and nephroprotective effect [17]. Their beneficial effect on health occurs only at considerable amounts of anthocyanins supplied regularly with diet. On a commercial scale, so far, they have been obtained mostly by extraction from grape pomace left after grape juice pressing. Additionally, in regions producing less wine, anthocyanins are obtained from chokeberry, blackcurrant, and elderberry. However, cornelian cherry (*Cornus mas* L.) is likely to become a very valuable source of anthocyanins. Cornelian cherry is known all over the world, but its commercial plantations are scarce. Countries that plant it on a noncommercial scale are Italy, France, Ukraine, Poland, Czechia, Slovakia, and Spain. Cornelian cherry has multiple natural habitats in Iran, Azerbaijan, Georgia, Turkey, and Serbia. The various possible uses and healthiness of cornelian cherries have recently increased interest in this plant among planters as well as scientists. Cornelian cherry fruits, in particular the dark ones, can be deemed a good source of anthocyanins. Most recent reviews focus on the health benefits of anthocyanins from cornelian cherry fruit [18–25]. The aim of this manuscript is to analyze the existing scientific developments in quantitative and qualitative assays of anthocyanins in cornelian cherry fruits and factors having an impact on their content. In addition, information was collected on their possible uses in the food, pharmaceutical, and cosmetic industries.

2. Methods

The databases of ScienceDirect, Elsevier, SciFinder, PubMed, Web of Science, and Google Scholar were used to search for literature containing keywords such as colorants, dye, anthocyanins, cornelian cherry (*Cornus mas* L.), and health properties. The search was limited to papers in English but with no limitations on the publication dates in the main text review. However, in the Introduction chapter, the search for colorants, dyes, and anthocyanins was limited to the years 2018–2023 (Figure 1). The literature search started in February 2023 and was finally updated on 15 December 2023. The publication timeline of the papers was from 1939 to 2023. To compare the results of different studies, the concentrations of anthocyanins were expressed in $mg \cdot 100\ g^{-1}$, and, where possible, included information on whether they were fresh weight (FW) or dry weight measurements (DW).

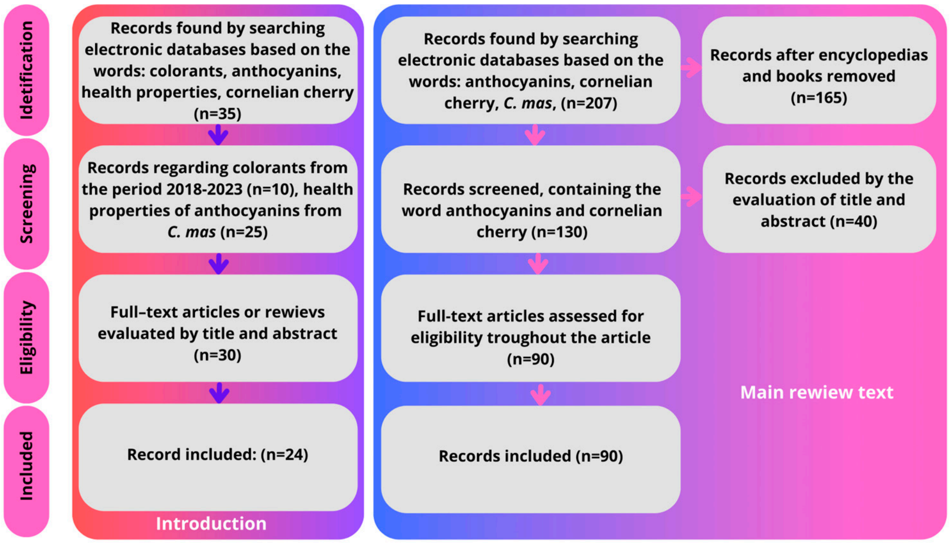

Figure 1. Flow chart describing the selection process of literature used in the review.

3. The Structure of Anthocyanins

Anthocyanins have a characteristic C6-C3-C6 carbon skeleton, but their structure is complex and differentiated. Their single basic core is the flavylium ion with different side groups (Figure 2).

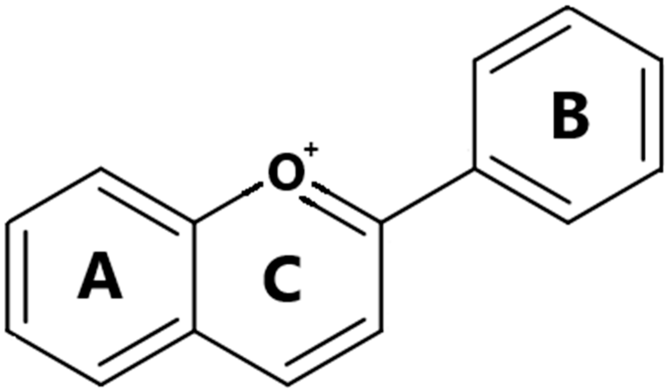

Figure 2. Flavylium cation backbone.

The side groups can be hydrogen atoms (-H), hydroxyl groups (-OH), or methoxyl groups (-OCH_3). Sugar substituents mostly include glucose and, less often, galactose, xylose, rhamnose, rutinose, and arabinose. Sugar radicals normally attach to the C3-hydroxyl group [26]. The core structure of anthocynins is anthocyanidine (aglycone), consisting of an aromatic ring A bonded to a heterocyclic ring C that contains oxygen. This ring is, in turn, bonded by a carbon-carbon bond to a third aromatic ring B. Anthocyanidins differ in terms of the position of methoxyl and hydroxyl groups on ring B. For instance, pelargonidin has only one hydroxyl ion, while cyanidin has two, and delphinidin has three (Figure 3).

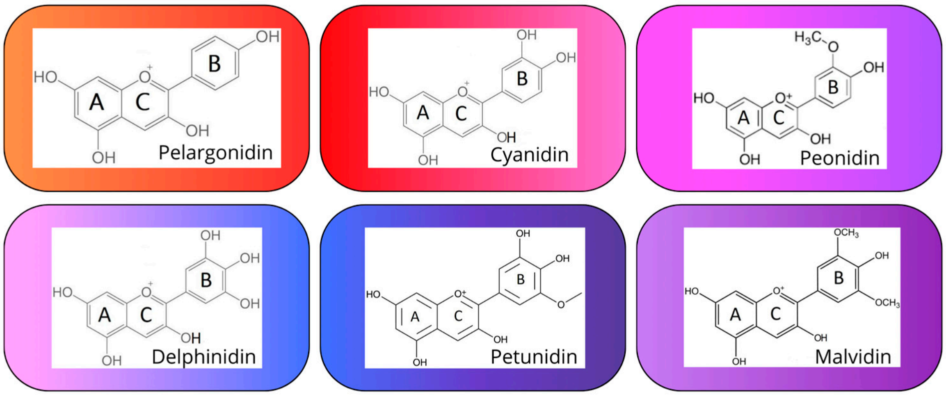

Figure 3. Patterns and color range of common anthocyanidins: pelargonidin (Pg), cyanidin (Cy), peonidin (Pn), delphinidin (Dp), petunidin (Pt), and malvidin (Mv).

More than 650 different anthocyanins were isolated in plants, with six possible structures of aglycones (anthocyanidins) most frequently occurring in natural conditions [27].

Anthocyanins are unstable in water, and their color depends on the pH of the solution (Figure 4). They will be red in acidic conditions and purple or blue in neutral or basic conditions. Furthermore, the intensity of anthocyanins coloration can change through copigmentation with metals, flavonoids, polyphenols, alkaloids, amines, and other anthocyanins. The intrinsic pigments of anthocyanidins and anthocyanins are related to their UV-visible spectral absorption, electronic coupling, and delocalization properties.

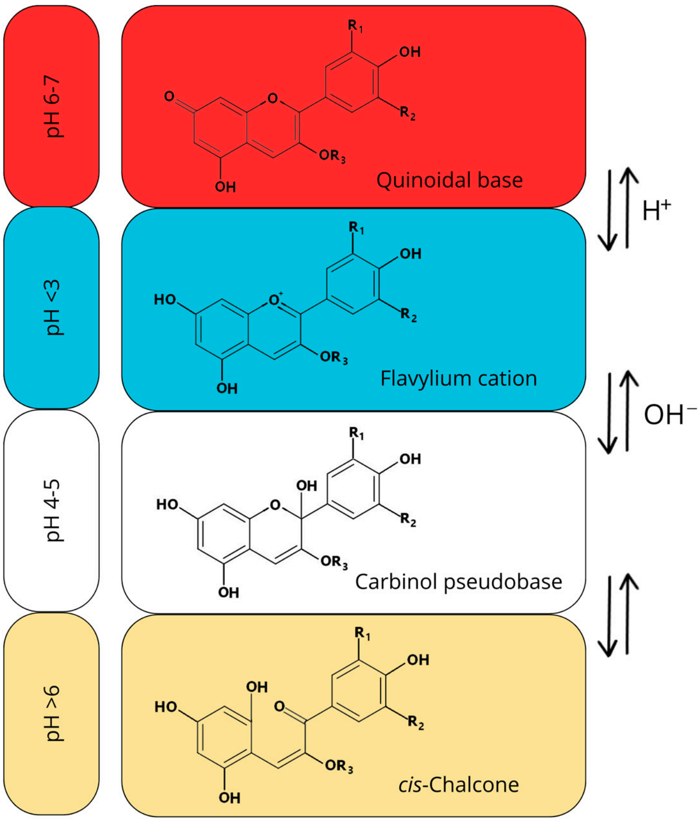

Figure 4. Chemical structures of anthocyanins and their color under different pH.

4. Methods for Extraction of Anthocyanin

Extraction is a very important stage prior to the anthocyanin assay. It involves the separation of polyphenolic compounds, including anthocyanins. The process is dependent on multiple factors, including the characteristics of the separated compounds (polarity, pH) and the solvents used. Anthocyanins feature low stability, so acidified water-based solutions of selected organic solvents are used. Most often, these are alcohol solutions containing ethanol or methanol, or possibly n-butanol, acetone, and propylene glycol. The extractant is acidified with hydrochloric acid or an organic acid, for instance, acetic acid [28].

Methods used to determine total anthocyanins vary depending on the literature. The principal method for quantifying anthocyanins is the pH differential method, which is widely used in industry since the procedure is rapid and easy to perform [29–31] and has high-performance liquid chromatography (HPLC), which in addition makes it possible to separate the mixture of anthocyanin compounds [32]. Other, less often used methods include the colorimetric method [33] and nuclear magnetic resonance [34].

Vakula et al. [35] used cornelian cherries as a raw material for the extraction of polyphenols with high antioxidant capacity by ultrasound-assisted extraction. The vacuum drying technique was applied to cornelian cherry drying in order to preserve as many chemical and biological compounds as possible. The lowest tested temperature and ethanol concentration (40 °C and 20%, respectively) and the extraction time of 60 min resulted in the lowest anthocyanin content in the extracts of dried cornelian fruits, while in the extract obtained at a temperature of 80 °C, 20 min and an ethanol concentration of 60%, the highest anthocyanin content was observed. It was found that shorter extraction times due to higher temperatures and ethanol concentrations had a positive effect on the anthocyanin content.

5. The Role of Anthocyanins in Plants

Anthocyanins, as plant pigments, have a signaling role for other organisms. Colorful flowers attract pollinators, but the function of a pronounced color is often to deter potential consumers. Anthocyanins in plants also have protective functions because they have antioxidant properties. They are also able to neutralize free radicals, i.e., atoms or molecules that have one unpaired electron in their valence shell. The antiradical activity of these compounds is increased by the number of hydroxyl groups in the B ring and the arylation of sugar residues with phenolic acids. Moreover, anthocyanins have the ability to chelate metal ions, e.g., iron and copper, due to the presence of hydroxyl groups in the C ring. An important feature of anthocyanin dyes is their ability to inhibit lipid peroxidation and fatty acid autoxidation. The content of anthocyanins is high in the tissue of alpine plants, which implies that they have a UV protective effect and thus prevent DNA damage and ensure the correct synthesis of proteins and cell division [36]. Oberbaueri and Starr [37] pointed out that in the evergreen plants of the tundra, anthocyanins are found in the outer palisade cells, which is consistent with the protective role of photosynthetic tissues against radiation. Anthocyanin concentrations increase when plants remain under snow cover and peak shortly after the spring thaws, when radiation levels are highest but temperatures remain low. Anthocyanins, due to their antioxidant properties, counteract the effects of oxidative stress also caused by high temperatures or lack of water or nutrients. Mechanical damage to plants caused by attacks by pests or diseases also results in the accumulation of anthocyanins.

The most common anthocyanin in fruits is cyanidin 3–glucoside (Cy-glu). Eggplants are an example of fruits not containing cyanidin glycosides but mostly derivatives of delphinidin [38]. Individual species of fruits can contain several, or even more than ten, anthocyanins of different colors. Figure 5 shows the content of all anthocyanins in the popular fruits of the temperate climate zone. Among the analyzed fruits, most anthocyanins occur in the darkest, almost black fruits, such as elderberry, followed by chokeberry, red grapes, blueberry, bilberry, and blackcurrant.

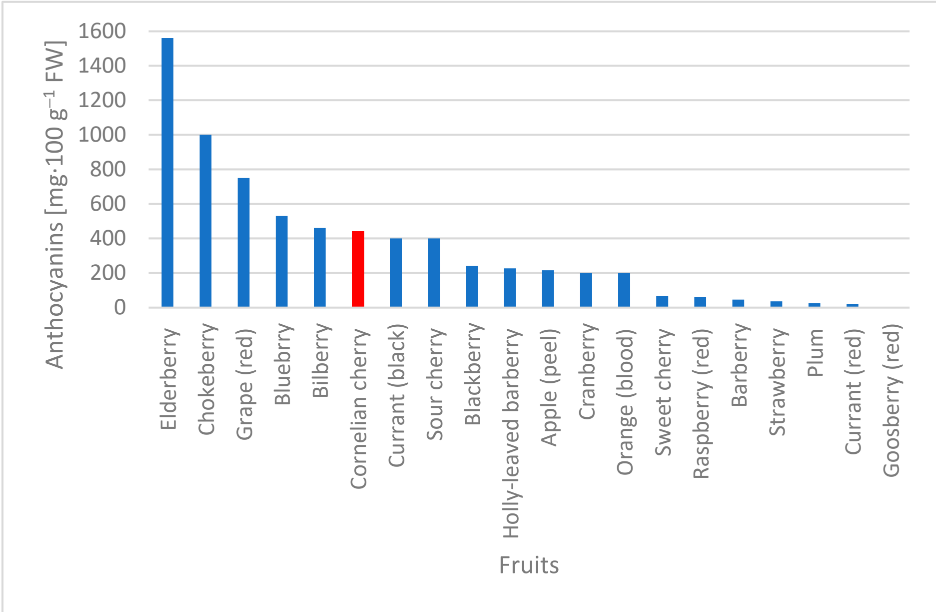

Figure 5. Total anthocyanin content in selected fruits (blue bars) compared to cornelian cherry (the red bar). Own study based on literature: [29,31,39–44].

6. Cornelian Cherry Fruit as the Source of Anthocyanins

Cornelian cherry fruits are juicy drupes with a sweet and sour taste and distinct flavor. The fruits can be round, oval, slightly elongated, pear-shaped, bottle-shaped, or elongated. Fruit length ranges from 1 to 4 cm, and the diameter is ca. 2 cm. Their color can be white, yellow, pink, red, cherry, or almost black (Figure 6).

Figure 6. Variations in fruit color among cornelian cherry cultivars.

6.1. Total Anthocyanin Content

The first scientific research on the content of anthocyanins in cornelian cherry fruits in 1939 [45] corroborated the results of many years of research on bioactive compounds. Anthocyanin content varies depending on the fruit cultivar and origin. Cetkovská et al. [31] compared the anthocyanin content of several fruit cultivars and recorded the lowest values for 'Joliko' (6.1 mg·100 g^{-1}), and the highest for cv. 'Lukjanovskij' 34.7 (mg·100 g^{-1}). Also, Bijelić et al. [46] comparing the total anthocyanin content of fruits, noticed significant differences between genotypes (from 36.35 to 116.38 mg·100 g^{-1}). Szot et al. [47] compared the anthocyanin content of more than ten ecotypes of cornelian cherry and evaluated that it ranged from 98.7 to 290 mg·100 g^{-1} FW. The anthocyanin content of cornelian cherry fruits sourced from Turkey, Serbia, Czechia, Poland, Iran, and Russia ranged from 6.1 to 427.75 mg·100 g^{-1} [31,48–56].

The anthocyanin content of cornelian cherry fruits depends on whether researchers calculate it per fresh or dry weight. The anthocyanin content in fresh weight ranged from 4.6 to 442.11 mg·100 g^{-1} FW and in dry weight 146.12 mg·100 g^{-1} DW (Table 1).

Table 1. Total anthocyanin content of cornelian cherry (*Cornus mas* L) fruits, according to various scientific sources.

Σ Anthocyanins	Origin of the Cornelian Cherry Fruits Used in the Experiment	Methods of Extraction	Source
49.94 mg·100 g^{-1} FW	Fruits of cornelian cherry from the Arboretum and Institute of Physiography in Bolestraszyce, Poland.	To 5.00 g of fruit pulp, 10 mL of 805 methanol acidified with hydrochloric acid were added.	[40]
117 mg·100 g^{-1} FW	Fruits of a cornelian cherry were collected in Riparbella (PI), Italy.	Lyophilized fruits of *C. mas* (280 g) were defatted at room temperature with n-hexane and extracted with MeOH by exhaustive maceration (5 × 500 mL) to yield 178 g of residue, which was dissolved in water and partitioned first with EtOAc and then with n-BuOH.	[57]
134.71 mg 100 g^{-1} FW	Fruits of genotype 'Chieri' located in the germplasm repository of the Department of Agricultural, Forest and Food Sciences of the University of Turin in Chieri, Piedmont (north-western Italy).	No data availble	[58]
138.32 mg·100 g^{-1} FW	Wild cornelian cherry fruits were collected in the Vlasina region of southeast Serbia.	The fresh fruits (10 g) were crushed in a grinder for 2 min, extracted three times a with 35 mL acidified methanol solution (formic acid/methanol/water, 0.1/70/29.9, *v*/*v*/*v*%) in a magnetic stirrer for 24 h in the dark, and then centrifuged for 10 min at 4000 rpm. The extracts were combined and purified through a 0.45 µm syringe filter (Millipore) before analyses.	[29]
146.12 mg·100 g^{-1} DW	Wild cornelian cherry fruits were collected in a forest in Kosovo.	The fresh cornelian cherry (*Cornus mas* L.) fruits were extracted and acid hydrolyzed using an acidified aqueous solvent of EtOH 96%/0.1% HCl (1:1, ratio) at room temperature for 4 h in the dark.	[59]
92–163 mg·100 g^{-1} FW	Wild cornelian cherry fruits were collected in Bosnia and Herzegoivina.	Additionally, 200 g of fruit sample was extracted with 80% ethanol (250 mL) using a Soxhlet extractor. After extraction (6 h), the samples were evaporated until dryness in a rotary vacuum evaporator (50 °C). The obtained extracts were kept at −18 °C until analysis.	[60]

Table 1. *Cont.*

Σ Anthocyanins	Origin of the Cornelian Cherry Fruits Used in the Experiment	Methods of Extraction	Source
223 mg·100 g^{-1} FW	Native fruits of cornelian cherry were collected from Mount Vermio, Northern Greece.	Prechilled fruit was ground with a pestle and mortar and placed on dry ice. The resulting tissue powder was well mixed with chilled acetone, placed in a freezer for 15 min, and then centrifuged at 20,000× *g* at 4 °C for 15 min. The pellet was dried under vacuum and extracted at 4C by gentle stirring with 100 mM sodium borate buffer (5 mL·g^{-1} fresh weight), pH 8.8, containing 5 mM ß-mercaptoethanol, 2 mM EDTA, and acid-washed polyvinylpolypyrrolidine at 10% the fresh weight. After 1 h, the solution was filtered through one layer of nylon cloth and centrifuged as above.	[42]
145.54–276.61 mg·100 g^{-1} DW	Fruits of cornelian cherry cv. 'Bordo' procured from the local market (Roman, Neamt, Romania).	An amount of 1 g of freeze-dried cornelian cherry powder was mixed with the designated volume of ethanol of varying concentration and introduced in an ultrasonic bath equipped with a digital control system of sonication time, temperature, and frequency. UAE was performed at a constant frequency of 40 kHz, with a constant power of 100 W. Cold water was added to maintain a constant temperature (±3 °C) in the ultrasonic bath. Afterwards, the supernatant was separated by centrifugation at 9000 rpm for 10 min. The collected supernatant was dried at 40 °C using a vacuum rotary evaporator (AVC 2-18, Christ, UK). The dried extracts were stored at 4 °C prior to subsequent analysis.	[61]
98.7–290 mg·100 g^{-1} FW	Fruits of ecotypes of cornelian cherry from a plantation in Dąbrowica, south-east Poland.	Additionally, 150 g of flesh from fresh cornelian cherry fruits was crushed and extracted with acidified 80% methanol.	[47]
5.8–302.9 mg·100 g^{-1} FW	Fruits of 10 genotypes of cornelian cherry from Vojvodina province, northern Serbia.	Each sample consisted of 50 fruits per genotype (fruit mesocarp). All samples were dried at 40 °C in the dark. Extraction methodology was used, with 80% EtOH (in water) as an extractant, and for TPC, with acidic ethanol (0.1 mol/dm^3 HCl in EtOH) as an extractant.	[62]
134.57–341.18 mg·100 g^{-1} DW	Fruits of 19 cultivars from Arboretum and Institute of Physiography in Bolestraszyce, near Przemyśl, Poland, 7 cultivars were harvested in the National Botanical Gardens of the Ukrainian National Academy of Sciences, Kiev, Ukraine, 3 cultivars were harvested in the Research Station for Cultivar Testing in Zybiszów, near Wrocław, Poland, 2 cultivars were harvested in the Warsaw University Botanic Garden, and 2 ecotypes ('Czarny', 'Jurek') were harvested in the Wrocław University Botanical Garden, Wrocław, Poland.	Frozen ripe fruits of cornelian cherry (*C. mas* L.) (1 kg) were shredded and heated for 5 min at 95.8 °C using a Thermomix (Vorwerk, Wuppertal, Germany). The pulp was subsequently cooled down to 40.8 °C and depectinized at 50.8 °C for 2 h by adding 0.5 mL of Panzym Be XXL (Begerow GmbH & Co., Darmstadt, Germany) per 1 kg. After depectinization and the removal of stones, the pulp was pressed in a Zodiak laboratory hydraulic press (SRSE, Warsaw, Poland). The pressed juice was filtered and run through an Amberlite XAD-16 resin column (Rohm and Haas, Chauny Cedex, France). Impurities were washed off with distilled water, while pigments and iridoids were eluted with 80% ethanol. The eluate was concentrated under vacuum at 40.8 °C.	[49]

Table 1. *Cont.*

Σ Anthocyanins	Origin of the Cornelian Cherry Fruits Used in the Experiment	Methods of Extraction	Source
4.06–427.75 mg·100 g^{-1} FW	Fruits of five Ukrainian cultivars from the National Botanical Gardens of the Ukrainian National Academy of Sciences, Kiev, Ukraine.	Before analysis, the stones were manually removed, and the fruits without stones (300–350 g) were homogenized. The amount of approximately 5 g of homogenized fruits (combined from three trees for each cultivar) was extracted with 80% aqueous methanol (*v*/*v*) and acidified with 1% HCl to a final volume of 50 mL at room temperature. The extraction was performed in an ultrasonic bath (Polsonic, Warsaw, Poland) for 15 min.	[50]
106.89–442.11 mg·100 g^{-1} FW	Fruits of six cornelian cherry genotypes were collected in a fruit garden in east Azerbaijan Province (Arasbaran).	Some frozen tissue was ground to a fine powder under liquid nitrogen by a cold mortar and pestle, and 1 g of the resultant powder was added to 10 mL of methanol containing HCl (1%, *v*/*v*) and held at 0 °C for 10 min. The slurry was centrifuged at 17,000× *g* for 15 min at 4 °C, and then the supernatant was used.	[48]

6.2. Differences in the Content of Individual Anthocyanins Depend on Genetic Characteristics

The fruits of individual cultivars of *Cornus* differ in anthocyanin content. Vareed et al. [63] compared the anthocyanin content of *C. mas* and *C. officinalis*, *C. controversa*, *C. alternifolia*, *C. kausa*, and *C. florida*. They identified six anthocyanins, while the fruits of *C. mas* and *C. officinalis* contained identical anthocyanins: Dp-gal, Cy-gal, and Pg-gal (expansion of abbreviations in Table 2), but their content was considerably higher in *C. mas*. The above cultivars of fruits did not contain Dp-glu and Dp-rut, which, in contrast, occurred in *C. alternifolia* and *C. controversa*. The fruits of *C. mas* and *C. officinalis* did not contain Cy-glu either, in contrast to *C. alternifolia*, *C. controversa*, *C. kousa*, and *C. florida*. Antolak et al. [64] found that Cy-glu was present in the fruits of *C. mas*; however, its levels were considerably lower than those recorded in *Vaccinium vitis—idaea* and *Sambucus nigra*. Capanoglu et al. [65] also identified Cy-glu in *C. mas* at amounts similar to those found in *Prunus laurocerasus* and significantly higher than in *Prunus cerasus*. The results of the above studies suggest that differences in fruit composition can be due to the genetic traits of plants and climate conditions in a specific region. As described, the genetic traits of plants, together with sun exposure, temperature, humidity, availability of nutrients, and the general qualities of soil, can affect the level of individual anthocyanins and the content of polyphenols in general [49,64]. Differences in the concentration of anthocyanins and organic acids between the tested cultivars and genotypes were pH-dependent. Babaloo and Jamea's [66] results on cornelian cherry fruits cv. 'Macrocarpa' showed that the most hyperchromic effect of all organic acids was observed at pH 2. These changes were not accompanied by changes in the bathochrome, and most changes were observed at pH 4.

Table 2. Individual anthocyanin content of cornelian cherry fruits.

No	Name of the Anthocyanin	Content	Source
1.	cyanidin 3-*O*-galactoside (Cy-gal)	3.82 mg·100 g^{-1} FW	[67]
		28 mg·100 g^{-1} of FW	[57]
		4.63–130.93 mg·100 g^{-1} FW	[68]
		3.82–166 mg·100 g^{-1} FW	[69]
		6.3–288.6 mg·100 g^{-1} FW	[70]
		20.26–22.62 mg·100 g^{-1} DW	[52]
		759.2 mg·100 g^{-1} of DW	[71]
		21.89–969.20 mg·100 g^{-1} DW	[72]
		5.6 g·100 g^{-1}	[73]
		20.9–29.7 mg·100 g^{-1}	[74]
		100.7 mg·100 g^{-1}	[29]
		0–234.4 mg 100 g^{-1}	[49]

Table 2. *Cont.*

No	Name of the Anthocyanin	Content	Source
2.	cyanidin 3-*O*-β-galactopyranoside (Cy-galpyr)	10.79 mg·10 g^{-1} FW	[75]
3.	cyanidin 3-*O*-glucoside (Cy-glu)	4.4 mg·100 g^{-1} DW 103.6 mg·100 g^{-1} DW 0.28 μg·mL^{-1}	[65] [61] [64]
4.	cyanidin glucoside-rutinoside (Cy-glurut)	11.8 mg·100 g^{-1} DW	[65]
5.	cyanidin 3-*O*-robinobioside (Cy-rob)	0.67–21.47 mg·100 g^{-1} FW 2.93–3.31 mg·100 g^{-1} DW 223.2 mg·100 g^{-1} of DW 0–45.32 mg·100 g^{-1} 0.321 μg·mL^{-1}	[68] [52] [71] [49] [64]
6.	cyanidin 3-*O*-rutinoside (Cy-rut)	11.7 mg·100 g^{-1} DW 180.60 mg·100 g^{-1} DW 6.83–11.59 mg·100 mL^{-1} FW 0.2–4.7 mg·100 g^{-1} 35.1 mg·100 g^{-1}	[65] [61] [53] [74] [73]
7.	delphinidin 3-*O*-galactoside (Dp-gal)	0.58–0.79 mg·100 g^{-1} DW 0.19–29.84 mg·100 g^{-1} DW 46.5 mg·100 g^{-1} DW 4.20–12.37 mg·100 mL^{-1} FW 4.91 mg·100 g^{-1} 0–16.68 mg·100 g^{-1}	[52] [72] [71] [53] [29] [49]
8.	delphinidin 3-*O*-β-galactopyranoside (Dp-galpyr)	2.8 mg·10 g^{-1} FW	[75]
9.	delphinidin 3-*O*-glucoside	0.22–24.29 mg·100 g^{-1} FW	[68]
10.	pelargonidin 3-*O*-galactoside (Pn-gal)	1.95–39.47 mg·100 g^{-1} FW 6.4–235.5 mg·100 g^{-1} FW 171.24–183.61 mg·100 g^{-1} DW 52.08–211.06 mg·100 g^{-1} DW 1570 mg·100 g^{-1} DW 0–104.82 mg·100 g^{-1}	[68] [70] [52] [72] [71] [49]
11.	pelargonidin 3-*O*-β-galactopyranoside (Pg-galpyr)	7.1 mg·10 g^{-1} FW	[75]
12.	pelargonidin 3-*O*-glucoside (Pg-glu)	32.73 mg·100 g^{-1} 58.62 mg·100 g^{-1} FW 87 mg·100 g^{-1} of FW	[29] [69] [57]
13.	pelargonidin 3-*O*-pentoside (Pg-pent)	0.39–0.47 mg·100 g^{-1} DW	[52]
14.	pelargonidin 3-rhamnosylgalactoside (Pg-rhamgal)	lack of data	[76]
15.	pelargonidin 3-*O*-robinobioside (Pg-rob)	0.38–3.18 mg·100 g^{-1} FW 3.21–10.06 mg·100 g^{-1} DW 249.3 mg·100 g^{-1} DW 0–6.30 mg·100 g^{-1} 0.302 μg·mL^{-1}	[68] [72] [71] [49] [64]
16.	pelargonidin 3-*O*-robinosideoside (Pg-rob)	19.15–20.41 mg·100 g^{-1} DW	[52]
17.	pelargonidin 3-*O*-rutinoside (Pg-rut)	2 mg·100 g^{-1} of FW 33.8 mg·100 g^{-1} FW	[57] [69]
18.	peonidin 3-*O*-glucoside (Pn-glu)	2.82–8.60 mg·100 mL^{-1} FW 17.9–69.6 mg·100 g^{-1}	[53] [74]
19.	petunidin 3-glucoside (Pt-glu)	0.380 μg·mL^{-1} 17.9–69.6 mg·100 g^{-1}	[64] [74]

Begic-Akagic et al. [74] compared the anthocyanin content of cornelian cherry fruits grown in three different regions, varying in terms of sun exposure and soil conditions. In cornelian cherry fruits, they found the highest content of Pn-glu, followed by Cy-gal, with Cy-rut being the lowest. Fruits from regions with high exposure to the sun contained considerably more Pn-glu and Cy-rut than fruits from the Visegrad area, where sun exposure is weaker. However, they recorded no differences in the content of Cy-gal. The researchers suppose that soil type might also be of significant importance. Van Leeuwen [60] found that soil and climate had more influence on the anthocyanin content of fruit than specific cultivar traits did.

Ochmian et al. [52] evaluated the effect of planting material on the anthocyanin content of several cultivars of cornelian cherry fruit. Fruits from trees that were shield-budded on *Cornus amomum* seedlings contained more anthocyanins than trees with their own roots. In particular, this concerned Dp-gal, Cy-gal, Pg-gal, and Pg-pen. They found higher levels of Pg than Cy in cornelian cherry fruit. The main anthocyanin was Pg-gal, followed by Cy-gal and Pg-robinosideoside. The content of Cy-rob, Dp-gal, and Pg-pe was much lower.

The different anthocyanin content of individual fruit cultivars is also associated with their different colors. Ripe fruits can be white, yellow, through pink, red, dark red, and almost black (Figure 6). Depending on the cultivar, the peel can be darker than the flesh or similar in color. Kucharska et al. [49] analyzed the content of anthocyanins in several cultivars of *C. mas*. As expected, the 'Czarny' ('Black') cultivar was characterized by the highest content of anthocyanins among the 28 tested cultivars, while the cv. 'Jantarnyj' contained no anthocyanins at all. In ten cornelian cherry cultivars, Kucharska [77] recorded the presence of five anthocyanins, mainly Cy-gal and Pg-gal. The content of Cy-rob and Pg-rob was much lower than that of galactosides. The fifth anthocyanin was Dp-gal. Cornelian cherry cultivars differed in the percentage of individual anthocyanins. Similarly, Sozański et al. [78] identified five anthocyanins in freeze-dried cornelian cherry fruits, with Cy-gal being predominant, followed by Pg-gal and Cy-rob. The content of Pg-rob and Dp-gal was much lower. Kucharska [77] and Dzydzan [71] did not note any anthocyanins in the yellow-colored fruit cultivars 'Flava' and 'Jantarnyj'. In another study by Kucharska et al. [49], the 'Czarny' cultivar had an outstanding content of Dp-gal, Cy-gal, and Cy-rob, while Cy-gal accounted for 69% of all anthocyanins. The lowest anthocyanins level was noted in fruits of the 'Koralovyj' cultivar that have a characteristic light pink color. Klymenko et al. [50], comparing the anthocyanin content of several fruit cultivars, namely *C. mas*, *C. officinalis*, and *C. mas* × *C. officinalis* hybrids, noted the previously mentioned anthocyanins: Dp-gal, Cy-gal, Cy-rob, Pg-gal, and Pg-rob. Among the examined *C. mas* cultivars, the 'Koralovyi' fruits contained the lowest amount of anthocyanins, and the black-colored 'Uholok' fruits the highest. The fruits of *C. officinalis* contained fewer anthocyanins than those of *C. mas* and *C. officinalis* hybrids. Martinović and Cavoski [68] compared the anthocyanin content of cornelian cherry fruit representing three local genotypes from Montenegro with four Ukrainian cultivars. The 'Kosten 1′ cultivar had an outstanding content of Cy-gal and Cy-rob. The local genotype (CT01) featured the highest content of Pg-gal. They observed that the predominant anthocyanin in the fruits from Montenegro was Cy-gal, while in Ukrainian cultivars it was Pg-gal. They were the only researchers to identify Dp-glu in local cultivars and genotypes of cornelian cherry, while Ukrainian cultivars did not contain that anthocyanin at all. Blagojević et al. [72] analyzed the anthocyanin content of four Serbian selections and three Ukrainian cultivars and found that Cy-gal and then Pg-rob were predominant. The content of Pg-rob and Dp-gal was the lowest. The cultivar with an outstanding content of particular anthocyanins was the Ukrainian 'Svetlyachok'. The main anthocyanins determined by Tural and Koca [54] in cornelian cherry fruits were Pg-glu, followed by Cy-glu, while the content of Cy-rut was the lowest. Moldovan et al. [69] comparing the anthocyanin content of cornelian cherry fruits sourced from the local market in Romania, found that Pg-glu was the most abundant, followed by Pg-rut, with the content of Cy-gal the lowest. Dumitraşcu et al. [61] observed that Cy-rut and Cy-glu accounted for 76% of all anthocyanins present in the extract of 'Bordo'—a Romanian cultivar of cornelian cherry. In contrast, Dzydzan et al. [71] identified five anthocyanins in the red-colored fruits of cornelian cherries, including three monoglucosides: Dp-gal, Cy-gal, Pg-gal and two diglucosides: Cy-rob, and Pg-rob. In addition, they found two aglycons: cyanidin and pelargonidin. These anthocyanin aglycons were formed after the detachment of sugars by hydrolysis during the extraction and purification of the fruit extract. Du and Francis [76] were the first to identify a disaccharide among anthocyanins in cornelian cherry fruit. This anthocyanin was cyanidin 3-rhamnosygalactoside.

The researchers determined several anthocyanins derived from cyanidin, pelargonidin, delphinidin, peonidin, and petunidin in cornelian cherry fruit. However, they did not record malvinidin at all.

6.3. The Effect of Cornelian Cherry Fruit Ripeness on the Anthocyanin Content

Gunduz et al. [79] examined changes in the anthocyanin content during fruit ripening. Fruits from light yellow, blush, through light red to dark red gradually increased their anthocyanin content from 4.9 μg Cy-3-glu$\cdot$g^{-1} FW (light yellow) to 65.8 μg Cy-3-glu$\cdot$g^{-1} FW (intense red). Szot et al. [47] also assessed the anthocyanins content of cornelian cherry fruits depending on fruit ripeness and found that green fruits contained no anthocyanin at all, light red fruits contained 12.6 mg$\cdot$100 g^{-1} FW, and fully ripe ones −140.6 mg$\cdot$100 g^{-1} FW. Turkish researchers [80] found that unripe fruits (<10% red skin color) contained four times less anthocyanins than those fully pigmented, and although during the storage of unripe fruits, anthocyanins were observed to accumulate, their content did not reach the level measured in fully ripe fruits.

6.4. Changes in the Anthocyanins Content after Fruit Harvest

Fresh fruits are the best foodstuff in terms of their abundance of healthy ingredients. The fruits of individual cultivars of cornelian cherry ripen, depending on the latitude, from mid-June to the end of October. Ilyinska and Klymenko [81] report that the earliest maturing cultivar, 'Vitivka Svitlany' needs 17,000 h of effective temperature for 80% of the fruit to ripen sufficiently to be picked. Cornelian cherry fruit has storage stability similar to that of sweet cherries [82].

The synthesis of anthocyanins in fruits continues even after they are harvested, especially if they are stored in the air, even at low storage temperatures [83,84]. Ebrahimzadeh et al. [85] examined changes in the anthocyanin content during the storage of cornelian cherry fruits at a temperature of 0, 5, 10, and 21 °C over three weeks. At any storage temperature, and, in particular, at 10 °C, the anthocyanin content increased with storage time.

However, Bahram et al. [86] stored cornelian cherry fruits at a temperature of 25 °C for 9 days and noted a nearly twofold decrease in the total anthocyanin content. They attributed this decrease to degradation of compounds in the presence of oxygen and their condensation with tannins and protein compounds.

Mohebbi et al. [82] stored cornelian cherry fruits at a temperature of 1 °C at 90–95% relative humidity and, after 7, 14, 21, 28, and 35 storage days, found a 7%, 13%, 30%, 32%, and 42% decline in the anthocyanin content, respectively. They attributed the decline in anthocyanin content to the increased pH of fruits. They observed that polypropylene and low-density polyethylene film for packing the fruits inhibited the decrease in anthocyanin content. They attributed this to a change in the gas conditions in containers covered with films of various gas permeabilities to CO_2 and O_2.

Aghdam et al. [87] claimed that cornelian cherry fruits treated with $CaCl_2$ after harvest featured an increased anthocyanin content in relation to the control fruits. They suggested a possible reason as being the activation of the phenylalanine ammonia-lyase (PAL) enzyme in the conditions of increased cytosol concentrations of Ca^{2+}.

Yarilgac et al. [80] investigated how the anthocyanin content changed in unripe fruits (red skin color < 10%) and in ripe fruits (red skin color > 90%) while storing the fruits in normal and modified conditions. They found an increased anthocyanin content of unripe fruit after 15 and 30 days of storage at a temperature of 0 °C, a relative humidity of 90–95%, and three days of storage at a temperature of 22 °C and 80% RH. However, fruits stored in controlled conditions developed fewer anthocyanins than when stored in normal conditions. Anthocyanin synthesis can be inhibited in fruits stored in high concentrations of CO_2. Holcroft and Kader [84] found a negative effect of the atmosphere on the anthocyanin concentration and on the activities of the key enzymes of the anthocyanin synthesis pathway: phenylalanine ammonia lyase and UDP-glucose: flavonoid glucosyltransferase. In contrast, ripe fruit stored in conditions identical to those for unripe fruit showed a gradual decline in the anthocyanin content, while the fruits stored in controlled conditions contained insignificantly more anthocyanins than when stored in normal conditions.

In cornelian cherries, anthocyanins occur not only in fruits (Figure 6), but they are also involved in the pigmentation of leaves in autumn (Figure 7). They sometimes appear in the tissues of plants exposed to adverse conditions such as drought, cold, nutrient deficiency, strong UV radiation, etc.

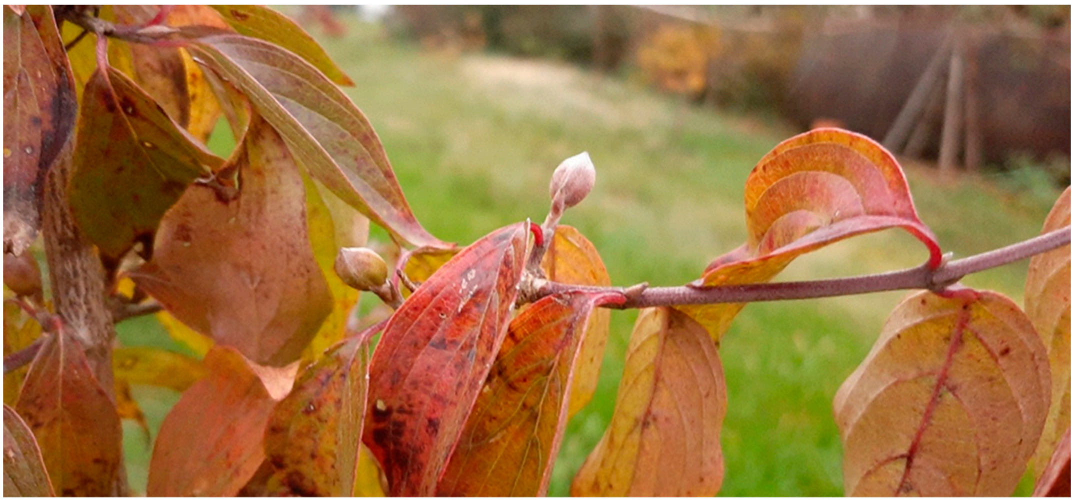

Figure 7. Orange and red pigmentation of the cornelian cherry leaves in autumn.

7. Uses of Cornelian Cherry and Presence of Anthocyanins in Cornelian Cherry Products

7.1. Anthocyanins in Food Products Derived from Cornelian Cherry

A good method of extending the utilization period of the anthocyanins contained in cornelian cherries is fruit processing. Drying is one of the oldest fruit-preserving methods. An experiment [88] was conducted in Turkey to optimize the sun-drying of cornelian cherry fruits. It did not concern changes in the anthocyanin content but demonstrated that drying leads to a 50% loss of vitamin C.

A very good way of extending the useful life of cornelian cherries is fruit freezing. Szczepaniak et al. [89], comparing the color of frozen cornelian cherry fruits and that of thawed fruits, found that the distribution of anthocyanin pigments can affect fruit color luminosity due to the relationship between the degradation of anthocyanins and the development of yellow pigments. This can be observed as a decline in the value of parameter a*. The color of anthocyanins in the presence of metal ions depends on the type of ions occurring in the environment and on the species of plants. Tin ions alter the color of strawberries, raspberries, and sour cherries and make blackcurrants violet and purple. Meanwhile, the presence of iron and copper ions resulted in brown coloring [90,91].

Cornelian cherry fruit can be used to make anthocyanin-rich juices. A basic operating unit in juice production technology is its concentration, which reduces the cost of storage, transportation, and packing and prevents microbiological spoilage. Naderi et al. [92], developing a technology of cornelian cherry juice concentration to 42°Brix, demonstrated that the best results can be achieved using a microwave and reduced pressure (12 kPa). The concentrate had the highest content of anthocyanins and tannins and featured the highest antioxidant capacity. Anthocyanins derived from cornelian cherry juice can improve the quality of food products. Salejda et al. [93] demonstrated that, due to anthocyanin content and the presence of other antioxidants, an addition of cornelian cherry juice effectively reduced the oxidation intensity of lipids in beef burgers during a five-month storage of the products in a frozen state.

Cornelian cherry fruit is used to produce jams and preserves, which, due to their tastiness, make a good add-on to desserts (cookies) and savory foods (in particular game dishes and cheeses). This processing method produces highly nutritive products, as corroborated by the study of Begic-Akagik [74], who recorded identical anthocyanin levels in cornelian fruit jam and in fresh fruits. However, after six months of storage, they observed a degradation of anthocyanins since the content of Pn-glu was 25% lower, Cy-gal 40% lower, and Cy-rut 15% lower. They believe that anthocyanin loss is due to a high sugar content, high acidity, and the presence of vitamin C. Due to high acidity, cornelian cherry jam is sweetened with up to 500–600 g of sugar per 1000 g of fruits. Kucharska [77], while processing cornelian cherry fruits, observed their high stability, which could be a result of acidic conditions and the protective effect of other compounds on anthocyanins. Significant loss of red pigments occurred after storing the jams for six months. The size of these losses was dependent on the product storage temperature. Reducing the storage temperature of cornelian cherry jam from 30 to 4 °C reduced anthocyanin loss from 93–98% to 11–36%.

Another cornelian cherry fruit processing method is to make paste from fully ripe fruits after removing the stone, mashing the flesh, and mixing it with sugar. Cornelian cherry paste, rich in anthocyanins, can be a natural color and flavor for desserts, for example, ice cream. Topdaş et al. [94] noted that cornelian cherry paste added to ice cream increased the flavonoid content and, thus, antioxidant activity. In addition, cornelian cherry paste increased the content of vitamin C and improved the sensory quality of ice cream.

Dried cornelian cherries can be ground to powder. Powdered cornelian cherries can improve the healthiness of various products. Šimora et al. [95] studied the possibility of using dried and powdered cornelian cherry fruits for baking bread. They showed that incorporating the powder at 1–10% w/w into the bread recipe significantly improved the bioactive and sensory properties of the bread. They demonstrated that the 5% replacement of wheat flour in the bread recipe had no negative impact on the key physical and sensory properties while increasing the concentration of phenolic antioxidants.

Turkish researchers [96] demonstrated the possibility of increasing the healthiness of white chocolate by adding 2% of powdered cornelian cherries. Due to the high content of phenolic compounds (including anthocyanins), powdered cornelian cherry significantly increased the oxidative capacity of white chocolate.

Anthocyanins can be used as food colorants, labeled E 163 according to the EU alphanumeric system. Most often, they are obtained from red cabbage, eggplants, and grape skin. The red and purple pigments are used for coloring, among other products, powdered orangeade, soft drinks, ice cream, wine, yogurt, candies, and other sweets. Anthocyanins as a natural food color make an excellent option for the food industry, but their very low stability in food products presents a limitation. Copigmentation is a way of stabilizing and increasing color intensity. This phenomenon involves creating flavonoid complexes, phenolic acids, and other substances containing anthocyanins, both in the colored cells of plants and in fruit products. Copigmentation is the interaction between anthocyanins and copigment particles, modifying their color and stability. The copigment significantly preserves the color of anthocyanins as it prevents the formation of a colorless falvylium cation. Babaloo and Jamei [66] found that caffeic acid was the most effective co-pigment for maintaining the stability of cornelian cherries anthocyanins compared to tannic, benzoic, and coumaric acids. Moldovan and Dawid [97] demonstrate that anthocyanins derived from cornelian cherry are more durable than those from other sources, e.g., blackberries, due to the good storage stability stemming from the specific structure of cornelian cherries.

Due to their antibacterial properties, anthocyanins derived from cornelian cherry can be used as food preservatives. Antolak et al. [64] report that cornelian cherry juice eliminates the gram-negative bacteria from acetic acid, *Asaia* spp., featuring a strong adhesion capacity, as it has anti-adhesive properties and reduces relative adhesion (on average by

77%). Krisch et al. [98] compared the anti-bacterial properties of juice and expeller of fruits representing the following families: *Rosaceae*, *Grossulariaceae*, *Moraceae*, *Berberidaceae*, *Caprifoliaceae*, *Polygonaceae*, and *Cornaceae*. Out of 21 evaluated species, *Cornus mas*, *Sorbus aucuparia* and *Ribes nigrum* showed the best inhibitory effect on the growth of *Bacillus subtilis*, *B. cereus var. mycoides*, *Eschrichia coli*, and *Serratia marcescens*. Milenković-Anđelković et al. [29] investigated the effect of cornelian cherry fruits on the survival rate of gram negative strains: *Escherichia coli*, *Pseudomonas aeruginosa*, *Salomo-nella enteridis*, *Shigella sonnei*, *Klebsiella pneumoniae*, *Proteus vulgaris* and gram-positive strains: *Clostridium perfingens*, *Bacillus subtillis*, *Staphylococcus aureus*, *Listeria innocua*, *Sorcina lutea* and *Micrococcus flavus.* The diameters of zones in which bacterial growth was inhibited under the influence of cornelian cherry extracts (50 µL/disc) ranged from 11.1 to 15.4 mm, which is quite significant compared to reference antibiotics (from 16.0 to 38 mm). Cornelian cherry extract was particularly effective in attenuating gram (+) bacteria *Listeria innocua*, and gram (−) negative bacteria such as *Pseudomonas aeruginosa* and *Klebsiella pneumoniae*. Another experiment by Kyriakopoulos&Dinda [99] revealed a strong anti-microbial effect of *C. mas* extracts on both gram-positive, and gram-negative bacteria: Staphylococcus aureus and *Pseudomonas aeruginosa*. This effect was explicit after sodium bromide was added in the extraction procedure and varied depending on ion availability. Anthocyanins and chalcones present in cornelian cherry fruits produce flavylium derivatives, playing an essential role in their bactericide effect. Odžaković et al. [60] evaluated that anthocyanin content of cornelian cherries harvested from the natural habitats in Bosnia and Herzegovina was strongly correlated with antibacterial properties in relation to *Baccillus cereus* and *Escherichia coli*; however, no significant correlations were identified for *Staphylococcus aureus* and *Pseudomonas aeruginosa*. Yigit [100] explored the effect of water-based and methanolic extracts of cornelian cherry on bacteria such as *Entorobacter aerogenes*, *Escherichia coli*, *Proteus mirabilis*, *Pseudomonas aeroginosa*, *Staphylococcus aureus*, and yeasts: *Candida albicans*, *C. glabrata*, *C. krusei*, *C. parapisilosis*, and *C. tropicalis.* Both extracts showed the best antibacterial effect on *S. aureus*. In contrast, only methanolic extracts of cornelian cherry had an antifungal effect on the tested clinical isolates of human pathogens. Haghani et al. [101] emphasized that anthocyanins have indicated protective effects on the viability of probiotics that can reduce the damage to probiotic cells when exposed to the rough conditions of gastrointestinal digestion. In their study, they developed functional ice cream containing different concentrations of peel from *C. mas* and *Bifidobacterium lactis* and indicated that the use of this peel could improve the viscosity, antioxidant activity and nutritional value of the ice cream. Additionally, thanks to the presence of anthocyanins, the survival of *B. lactis* increased during 120 days of storage and in simulated gastrointestinal conditions. They found that peel form cornelian cherry fruit is a valuable functional ingredient in ice cream recipes, while maintaining the sensory acceptability and viability of probiotics.

An old use of the fruits is the production of liqueurs. Cornelian cherry liqueur is a long-maturing product since it is not before three months that alcohol can extract active compounds from the fruits. With time the liqueur tastes of caramel but not of almonds as is characteristic of liqueurs made from other drupes such as sour cherry and apricot. Liqueurs also contain many valuable compounds, including anthocyanins, derived directly from the plant. Enthusiasts of liqueurs produce them for an interesting taste or due to their healthy properties. Kucharska et al. [102] evaluated the production capacity and quality of cornelian cherry liqueurs depending on how the fruits are obtained. They noted that sugar should be added at later stages of liqueur making to increase its polyphenol content. Fruits should be jabbed and, without removing the seeds, poured with alcohol at a concentration exceeding 40% (optimally 60–70%) to obtain a polyphenol-rich liqueur. This procedure can additionally induce the extraction of active compounds from fruit seeds. It is worth noting that cornelian cherry seeds do not contain amygdalin, in contrast to the seeds of various *Prunus* fruit (sour cherries, sweet cherries, and plums), so there is no need to remove them quickly from liqueurs for fear of hydrocyanic acid being formed. The liqueurs change color with storage time. Kucharska et al. [102] found that liqueurs, compared with fresh cornelian cherry fruit, contained low amounts of anthocyanins (from 0.155 to 1.052 mg·100 mL^{-1} after three months of storage). After only three months of liqueur storage, they observed almost complete degradation of anthocyanins. The anthocyanin degradation index was high—from 2.1 to 2.8 after six months and from 3.2 to 6.2 after nine months of storage. Maturing changed the color of the liqueur, which became less red (lower a*) and more yellow (higher b*). A high correlation (r = 0.89) was observed between the anthocyanin content and parameter a*. After six months of storage, the analyzed liqueurs contained from 1819 to 2457 mg·L^{-1} polyphenols. Rødtjer et al. [103] observed a similar polyphenol content of sour cherry liqueur (1080–1525 mg·L^{-1}), while a liqueur from green (unripe) walnuts contained from 2001 to 3522 mg·L^{-1} polyphenols [104].

Cornelian cherry juice can be used in the production of fruit-flavored beer. Kawa-Rygielska et al. [105] examined the physicochemical and antioxidant properties of beer with an addition of juice from cornelian cherry cultivars 'Jantarnyj', 'Koralovyi' and 'Podolski'. They identified the following anthocyanins in beer prepared with an addition of red fruits of cornelian cherry: Dp-gal, Cy-gal, Cy-rob, Pg-gal and Pg-rob. It transpired that Cy-gal and Pg-gal were predominant anthocyanins. Anthocyanins are relatively unstable and prone to degradation under the influence of several factors, including storage temperature, pH, and access to oxygen and light, so their concentration declines after fermentation. Therefore, it is recommended that cornelian cherry juice be added after fermentation is completed [106]. Then, the drink will be rich in five anthocyanins: Dp-gal, Cy-gal, Cy-rob, Pg-gal, and Pg-rob. The predominant anthocyanin was Pg-gal, accounting for 51% of the total content of these compounds, followed by Cy-gal (24%).

Another popular use of fruits is vinegar production. Vinegar is produced during the fermentation of juice, and its quality depends on the raw material used, acetylation methods, and ripening procedure. The anthocyanin content of vinegar depends on the fruit cultivar [107], the method (single-stage/spontaneous) of alcohol and vinegar fermentation in controlled oxygen conditions, and two-stage fermentation, where alcohol fermentation is first induced by the yeast strain *Saccharomyces bayanus*, and then spontaneous vinegar fermentation is allowed. Four anthocyanins were identified in red fruit vinegars. Higher concentrations of particular anthocyanins were measured in vinegar produced by two-stage fermentation.

In Greece, [108] an innovative drink was developed using cornelian cherry juice and probiotic bacteria. Probiotic food is beneficial to consumers' health as it fosters the growth of specific bacteria supporting intestinal processes and, simultaneously, inhibits the growth of pathogenic bacteria [109]. The probiotic *Lactobacillus plantarum* was used in free form and immobilized in a delignified wheat bran medium. Cornelian cherry juice was fermented for 24 h and then stored at 4 °C for four weeks. The resulting product had a low alcohol content of 0.3–0.9% v/v. The drink prepared from fermented cornelian cherry juice in the presence of immobilized bacteria featured a total polyphenol content that was 25% higher than that from the production using free bacterial cells. The polyphenol content of such juice was also 36% higher than in nonfermented juice.

Anthocyanins are easily degradable pigments [110], so technological processes should be very specifically adapted to reduce losses to the minimum.

7.2. Anthocyanins in Pharmaceuticals Derived from Cornelian Cherry

The therapeutic properties of anthocyanins are used in all world medicines. The anthocyanin extraction method is very important in making medicinal preparations. Tarko et al. [73] compared the efficiency of the extraction of polyphenols from plant materials (elderberry, Japanese quince, and cornelian cherry), depending on the type of solvent (water, methylene chloride, and 80% aqueous solutions of methanol or ethanol) and pre-treatment parameters (homogenization and microwave processing). The best results for the extraction of polyphenols were obtained using an 80% methanol solution, while water and methylene chloride were not suitable. Among the examined fruits, extracts obtained from cornelian cherry contained significantly lower amounts of the analyzed phenolic compounds. However, Dumitraşcu et al. [61] used ultrasound extraction to isolate anthocyanins from cornelian cherry fruits. The maximum anthocyanin recovery was observed after 40 min at a temperature of 30 °C, using an 80% water-based ethanol solution extractant. In Greece, [99] an innovative method was designed to extract brittle and unstable anthocyanins from cornelian cherry fruits using sodium bromide. The obtained medicinal preparations had considerable selective antibacterial activity, so they could help overcome the problem of common resistance to antibiotics.

Anthocyanins are substances of low stability, but their useful life can be extended by encapsulation. Encapsulated bio-active compounds are protected by the capsule wall material, due to which they can reach the target system. The structural elements of a capsule are the core and the medium. The type of wall material significantly affects encapsulation effectiveness and core features. An experiment in Romania [111] investigated the possible use of soy protein as capsule wall material for capsules containing powdered cornelian cherry fruit lyophilizate. The capsules were tested in simulated gastric digestion conditions. However, the outcomes were not satisfactory. It transpired that soy protein, without temperature preservation, could not be used as a capsule wall material because anthocyanins were not sufficiently protected in gastric juice. In addition, the high pasteurization and sterilization temperatures (121 °C) contributed to a drastic loss of anthocyanins. In another experiment [112], we compared the effectiveness of encapsulating anthocyanins derived from cornelian cherry juice using dry-freeze and spray-drying methods. Microencapsulation of anthocyanins from cornelian cherries was affected by the coating material and encapsulation technology. Encapsulation was the most effective with a spray-dried biopolymer combination of soy protein and maltodextrin. An in vitro study showed that a mix of coating materials facilitating a controlled release of anthocyanins into the intestines offers the best protection. Cornelian cherry powder obtained by spray-drying had nearly perfect spherosomes, in which the anthocyanins were retained as droplets coated by fine membranes. Anthocyanins can be used as pigments enhancing visual attraction, e.g., for vitamin pills.

7.3. Anthocyanins in Cosmetic Products Derived from Cornelian Cherry

Nizioł-Łukaszewska et al. [113] prepared an innovative hydrophilic and hydrophobic extract from cornelian cherry fruits, which can be used in the production of body balm. Both the hydrophilic and hydrophobic phases can neutralize free radicals due to the high polyphenol content. Cornelian cherry extract added to emulsions increased their stability and affected their rheological properties. Anthocyanins contained in the extract mono—and diglicosides of pelargonidin, cyanidin, and delphinidin—could contribute to the change in the white color of the emulsion. However, it was observed that the color of the body balm with a cornelian cherry extract did not change significantly compared with a standard body balm. A slight shift in color parameters was observed from green (−a) towards red (+a), which was accompanied by a slight decrease in yellow saturation (+b).

Anthocyanins are also the ingredients of antiaging cosmetics and preparations for couperose skin. The use of anthocyanins in cosmetics is mainly based on their ability to reinforce blood vessels and inhibit collagen degradation (due to UV radiation).

8. Conclusions

The content of anthocyanins in cornelian fruits is high and comparable to fruits considered to be the richest sources of these compounds, so they may be a good source of these natural colorants used in industry.

Quantitative and qualitative differences in the anthocyanin composition of cornelian cherry fruit imply that the genetic traits of the cultivar and the rootstock, the area in which the plants grow, and ripeness affect the content of active ingredients in fruits. Qualitative analyses of anthocyanins derived from cornelian cherries demonstrate that pelargonidins are predominant in some cultivars and cyanidins in others, but no malvidins were found in any case. Individual fruit cultivars contain three to five anthocyanins. The content of specific compounds determines color, shade, and stability. Most pink fruits contain the following anthocyanins: cyanidin 3-*O*-galactoside, pelargonidin 3-*O*-galactoside, pelargonidin 3-*O*-robinobioside, cyanidin 3-*O*-robinobioside, and delphinidin 3-*O*-galactoside, which are present in dark-colored fruits only (red, carmine, and almost black). However, it is necessary to carry out detailed research using a specific method of extraction and measurement of anthocyanins among different cultivars to be able to conclude that the presence of delphinidin 3-*O*-galactoside determines the darker color.

Dark-colored cornelian cherry fruits are a good source of anthocyanins in the human diet, both consumed fresh and processed into juice, purée, jam, paste, beer, or vinegar. Technological processes lead to the degradation of anthocyanins under the influence of heat, light, oxygen, sugar decomposition products, and other factors, but their loss can be prevented by adopting a suitable parameter range for these factors. Modern plant material processing methods such as freeze-drying and spray-drying offer the maximum protection of anthocyanins derived from cornelian cherry fruit and make it possible to use them in the production of functional foods and dietary supplements.

It has been repeatedly shown that anthocyanins from cornelian cherry fruit have antimicrobial properties against harmful fungi and bacteria, and on the other hand, they increase the survival of probiotic bacteria, so they can be used for food and pharmaceutical product preservation and the production of functional food.

The literature is rich in information regarding the amount of anthocyanins in cornelian cherry fruits, depending on genetic characteristics. Moreover, they are determined when examining the health-promoting properties of fruits. However, there is little experience on the impact of various cultivation methods on the content of these pigments in fruits. Therefore, researchers' efforts should focus on optimizing cultivation and care treatments while determining the broadly understood fruit quality, including the anthocyanin content.

Author Contributions: Conceptualization, I.S., G.P.Ł. and B.S.; methodology, I.S., G.P.Ł. and B.S.; resources, I.S., G.P.Ł. and B.S.; writing—original draft preparation, I.S., G.P.Ł. and B.S. writing—review and editing I.S., G.P.Ł. and B.S.; visualization, I.S., G.P.Ł. and B.S.; supervision, I.S., G.P.Ł. and B.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

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