Wiley
Journal of Food Biochemistry
Volume 2025, Article ID 8899523, 26 pages
https://doi.org/10.1155/jfbc/8899523

WILEY

Review Article

Exploring the Potential of Black Chokeberry (*Aronia melanocarpa*) as a Health-Enhancing Agent: A Comprehensive Overview

Hatice Duman,[1] Buket Üner,[1] Sümeyye Sarıtaş,[1] Ecem Bolat,[1] Yalçın Mert Yalçıntaş,[1] Arda Erkan Kalkan,[1] Furkan Eker,[1] Emir Akdaşçi,[1] Ahmet Alperen Canbolat,[1] Burcu Pekdemir,[1] Nil Kurtgöz,[1] Ecem Eğin,[1] İrem Şenel Akdağ,[1] Celal Can Varol,[1] Aslıhan Özbilen,[1] Fatih Sezer,[1] Özge Karakaş Metin,[1] Kemal Melih Taşkın,[1] Sercan Karav,[1] Charalampos Proestos,[2] Gülçin Emel Babagil,[3] Emel Oz,[4] Charles Brennan,[5] Maomao Zeng,[6] Mukul Kumar,[7] Tahra Elobeid,[8] and Fatih Oz[4,9]

[1]*Department of Molecular Biology and Genetics, Çanakkale Onsekiz Mart University, Çanakkale 17000, Türkiye*
[2]*Department of Chemistry Laboratory of Food Chemistry, School of Sciences, National and Kapodistrian University of Athens, Athens 15772, Greece*
[3]*Republic of Türkiye Ministry of Agriculture and Forestry Erzurum Directorate of Provincial Agriculture and Forestry, Erzurum 25000, Türkiye*
[4]*Department of Food Engineering, Agriculture Faculty, Ataturk University, Erzurum 25240, Türkiye*
[5]*School of Science, RMIT University, Melbourne, Victoria 3001, Australia*
[6]*School of Food Science and Technology, Jiangnan University, Wuxi 214122, China*
[7]*Department of Food Technology and Nutrition, Lovely Professional University, Phagwara 144411, Punjab, India*
[8]*Department of Human Nutrition, College of Health Sciences, QU Health, Qatar University, Doha 2713, Qatar*
[9]*Department of Food Engineering, Engineering Faculty, Kyrgyz-Turkish Manas University, Bishkek 720038, Kyrgyzstan*

Correspondence should be addressed to Sercan Karav; sercankarav@comu.edu.tr and Charles Brennan; charles.brennan@rmit.edu.au

Received 13 June 2024; Revised 14 January 2025; Accepted 10 May 2025

Academic Editor: Hassan Ahmadi Gavlighi

Black chokeberry, scientifically known as *Aronia melanocarpa*, is native to the eastern part of North America and belongs to the Rosaceae family, specifically falling within the Maloideae subfamily. A sour taste makes fresh chokeberries difficult to eat raw, but they are widely used in the food sector to make wines, fruit teas, juices, jams, jellies, and dietary supplements. Black chokeberries are a rich source of several bioactive compounds. It has been discovered that the fruits of *A. melanocarpa* exhibit a variety of bioactivities that may be advantageous to human health, such as antioxidant, antiobesity, anti-infective, antidiabetic, and liver- and heart-protective properties. However, to determine the therapeutic capacity, safety, and underlying mechanisms of action of black chokeberries, a comprehensive examination similar to other natural plants and medical items is required. This review provides a comprehensive overview of *Aronia* plants, covering aspects such as botany, cultivation, bioactive chemical composition, and therapeutic activities to explore their potential health benefits. The findings are expected to significantly influence future research, particularly in the development of functional food products centered around chokeberries.

Keywords: *Aronia melanocarpa*; black chokeberry; functional food; health-promoting agents

1. Introduction

Aronia are perennial shrubs belonging to the Rosaceae family. The genetic studies of *Aronia* species have provided insights into the genus's taxonomy, genetic diversity, and breeding potential. Commonly accepted *Aronia* species include *Aronia arbutifolia, Aronia melanocarpa, Aronia prunifolia,* and *Aronia mitschurinii*. To further explore the origins and genetic background of *A. mitschurinii,* amplified fragment length polymorphism (AFLP) analysis confirmed its hybrid origins between *Aronia* and *Sorbus*, providing clarity on this species' genetic lineage [1]. Another study, investigating the hybrid origin of *A. mitschurinii*, found that while morphological data could distinctly separate *A. melanocarpa* and *A. mitschurinii*, molecular markers (ITS2, rbcL, trnL-F, and LEAFY) were not sufficiently discriminatory to differentiate between these species. This underscores the need for more precise markers to understand the evolutionary history of the genus better [2]. In 2017, genomic microsatellite markers were developed for *A. melanocarpa*, demonstrating their utility across different *Aronia* species and highlighting the potential for marker-based selection in breeding approaches, with 20 polymorphic microsatellite markers reported in *A. melanocarpa*, *A. arbutifolia*, and *A. prunifolia* [3]. RAPD and ISSR markers were also used to explore the genetic diversity among *A. melanocarpa* cultivars, indicating a narrow genetic base within commercially significant cultivars [4]. A transcriptomic approach was used to analyze the transcriptome of 6 *A. melanocarpa* cultivar fruits, identifying biosynthetic genes from important secondary metabolites [5].

A. melanocarpa is characterized by glabrous or nearly hairless stems and leaves that are pale green on the underside and dark green and shiny on the upper surface. The oval leaves, which become scarlet, typically measure 2.5–7 cm in length and 2.5–3.5 cm in width, with an apex ranging from subacute to acuminate. *A. melanocarpa* can grow up to 3 m. The plant produces sweet-scented flowers with yellow to purplish red anthers and black, acid, and bitter-tasting fruits (pomes) (Figure 1(b)). Black fruits weigh an average of 0.5–2 g and have a diameter of 6–13 mm [6] (Figure 1(a)). It flowers from March to June and bears fruit from September to November, thriving in habitats like swamps, bogs, wet thickets, and moist forests, at elevations from 0 to 2000 m [7].

Among these species, *A. melanocarpa* (black chokeberry) typically grows in moist woodland areas, but it adapts well to a variety of soil types and climates, making it a popular choice for landscaping and commercial cultivation. Originally native to the eastern regions of North America, the chokeberry was introduced to Europe in the early twentieth century. Cultivated chokeberry varieties include "Viking," "Nero," "Galicjanka," "Hugin," "N," "Rubina," "Aron," "Hakkija," "Ahonnen," "Kurkumäcki," "Fertödl," and "Serina" [4, 8]. Chokeberry's edible portions are primarily its fruits [6]. Because of their astringent flavor, fresh, unprocessed chokeberry fruits are rarely consumed. However, in recent years, they have attracted increasing attention from researchers, the food industry, and consumers, leading to a rise in its cultivation and usage in various products such as juices, jams, preserves, wines, liqueurs syrups, jellies, teas, and dietary supplements [9, 10]. The significant concentration of antioxidants, vitamins, and minerals found in *A. melanocarpa* berries highlights their potential to offer a range of health benefits. These include reducing inflammatory responses linked to a number of chronic illnesses, preserving cardiovascular integrity by controlling lipid profiles and blood pressure, and enhancing immunological resistance to infections [11–13].

The countries that produce these products the most are Poland, Russia, Germany, the United States, Japan, and Canada [14]. Although Aronia originates from North America, the primary producers of black chokeberry ingredients and products are European countries. 90% of the world's black chokeberry production is made in Poland [15]. Poland produced 36,800 metric tons of black chokeberries in 2009, and this amount climbed progressively to an estimated 50,000 metric tons in 2013. Additionally, in Poland, the area under cultivation grew from 5100 ha in 2009 to 6000 ha in 2013 [15]. Besides, an average of 200 metric tons of black aronia is produced annually in the state of Saxony, Germany. As of 2018, Germany produced a total of 1434 tons of black chokeberry, the United States produced 2500 tons, and Turkey produced 130 tons [16].

The extensive review explores a range of topics related to *Aronia* plants, including botany, cultivation techniques, the chemical components of these plants that are bioactive, and an investigation of their potential therapeutic uses. By offering a comprehensive grasp of their various characteristics, the goal is to unearth any potential health benefits linked to *Aronia* plants. This thorough analysis is anticipated to add significantly to the body of knowledge, particularly in terms of guiding further research initiatives and promoting the development of functional food products that showcase the unique characteristics of *Aronia* plants.

2. *Aronia* Plant Tissue Culture and Botany

Although it is not consumed as a fresh fruit due to its astringent characteristics and bitter flavor, in the last few years, *Aronia* has become the most popular berry species for dietary supplement research. *Aronia* berries have a rich content of bioactive compounds that have health-promoting effects, such as polyphenols, vitamins, and minerals [6, 17–19]. Because of the high content of secondary metabolites and their contribution to health and well-being, *A. melanocarpa* berries are called "superberry" [20, 21].

In vitro studies on plants are essential for the science of plants, agriculture and biotechnology, biodiversity conservation, sustainability, and enhancing cultivation [22]. Modern developments in the field of biotechnology enable the use of tissue culture in economically important commercial plant production [23]. Plant tissue culture relies on

(a) (b)

Figure 1: Flower and fruits of *A. melanocarpa* (Urban Forestry Outreach & Research, University of Minnesota, https://trees.umn.edu/black-chokeberry-aronia-melanocarpa).

the inherent capability of plant cells to develop into complete organisms, known as totipotency [24]. This phenomenon occurs when a plant cell is provided with optimal micro-environmental conditions, including essential nutrients such as minerals, water, light, carbon sources, and air. For more than a century, plant tissue culture technology has played a pivotal role in enhancing and advancing plants. It facilitates the production of disease-free plant material, enables the creation of transgenic plants, and assists in the micropropagation of superior plants possessing highly desired chemical characteristics [25]. Consequently, this technology contributes to more consistent and uniform plant production processes.

Aronia contains various organic and phenolic acids such as flavonols, phenols, and citric acid [26]. The most straightforward way to propagate is by employing in vitro methods following micropropagation technology. If one or more species of *Aronia* plants are available, it is possible to propagate these plants by vegetative methods (Figure 2). “Viking” and “Nero” are widely common species that reproduce through vegetative reproduction [23]. Also, in vitro propagation of *Aronia* species is very easy using typical shoot propagation methods followed by rooting and acclimatization [27].

Axillary buds from mature, original plants can be used for culture. The months between February and April are a good time to collect plant material. Growth and differentiation begin after a 4-week culture period. In the black chokeberry culture, the optimum equilibrium between growth regulators (mg/L) in vitro is 1.0 6-benzylaminopurine (BAP) and 0.1 gibberellic acid (GA3) on a basic medium including macroelements and microelements MS (1962) and vitamins LS (1965) [28].

In a study they conducted in 2022, Valentina and Catiţa explained the culture method as follows: They washed explants of black chokeberry under the tap water with 2–3 drops of bleach, and for 5 min, they immersed nodal explants in 96% ethyl alcohol by volume and rinsed them with sterile distilled water, and for 10 mins, sterilized them in 6% calcium hypochlorite. After 3 times rinsing with sterile distilled water, they transferred the node explants to a culture medium. After an in vitro culture of 4 weeks, they transferred the latest black chokeberry shoots to the propagation medium. All processes were conducted in a horizontal laminar air flow hood. They used test tubes with 5 mL of medium for in vitro culture initiation [28].

In a recent study, 5 different propagation media were used with shoot tips used as explants in *Aronia* plants and the effects of different growth regulators were investigated. For this study, full-strength MS medium, 30 $g \cdot L^{-1}$ sucrose, and 6.5 $g \cdot L^{-1}$ agar were added to the nutrient concentration, and the pH was adjusted to 5.7 using 1 N NaOH or 1 N HCl. Indole-3-butyric acid (IBA), BAP, and GA3 served as plant growth regulators. Their results showed that using too high or too low BAP and GA3 negatively affected the number of shoots per explant. It was also observed that the number of nodes increases as the shoot length increases [29]. In another study conducted by Almokar and Pırlak in 2023, the tissue culture method was as follows: After surface sterilization of one-year-old cuttings, the explants were moved to MS medium with 1.0 $mg \cdot L^{-1}$ GA3, 3% sucrose, MS vitamins, and 8 $g \cdot L^{-1}$ agar culture tubes covering a volume of 10 mL. With 75 $\mu mol \cdot m^{-2} \cdot s^{-1}$ white, fluorescent light of 1500–3000 lux., cultures were incubated in a growth room at $25 \pm 1°C$. After 21 days, new *Aronia* shoots were moved to the medium containing 1.0 $mg \cdot L^{-1}$ 6-Benzyladenine (BA), and when the desired number was reached, the plants were transferred to the medium containing IBA (1.0 $mg \cdot L^{-1}$) throughout the rooting stage [29].

Growth regulators and their concentrations play a very complex role in the accretion of secondary products. The sort and concentration of auxin or cytokinin, or the auxin/cytokinin ratio, cause remarkable changes in the form of development and product in cultured plant cells. 2,4-Dichlorophenoxy acetic acid (2,4 D) has been shown to

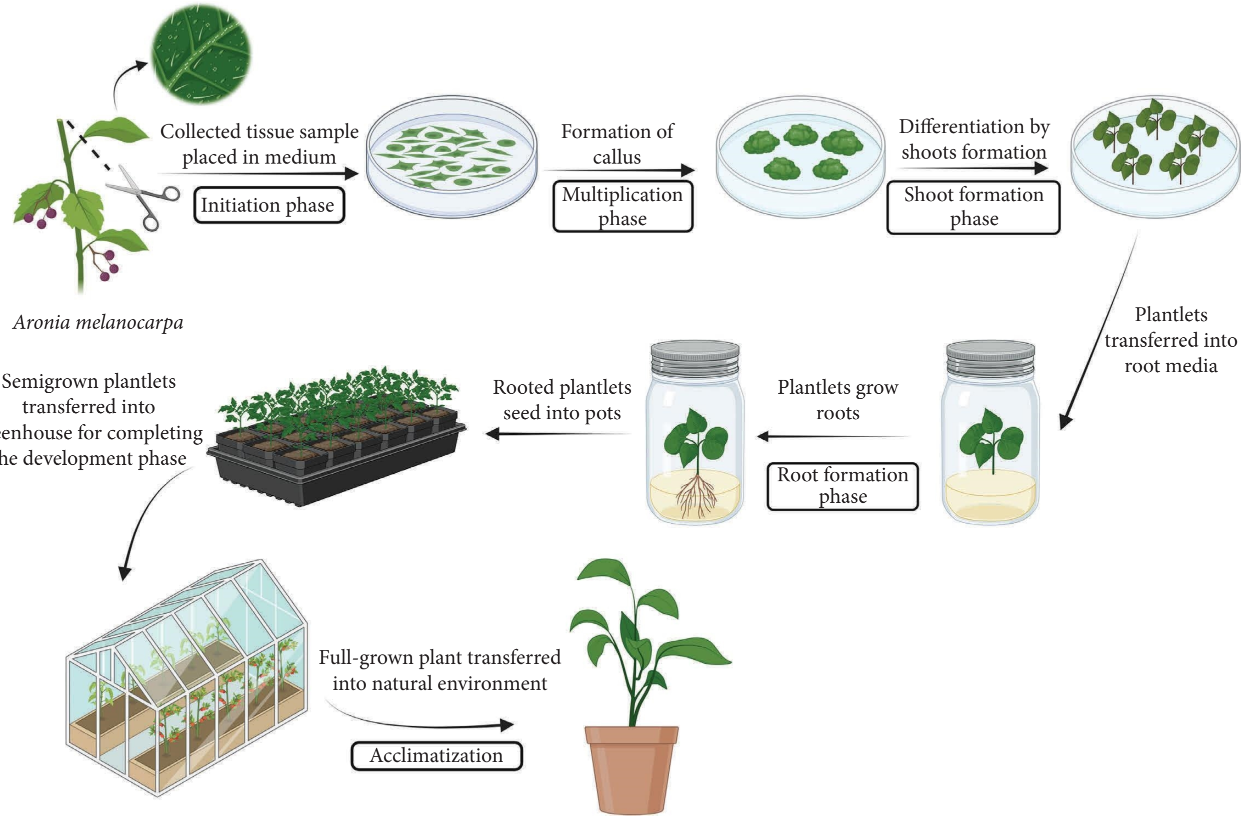

Figure 2: Representation of *Aronia* micropropagation [23].

inhibit secondary metabolite production in many cases. Abscisic acid (ABA) and GA3 have been reported to inhibit anthocyanin production in many cell cultures [30]. In a study performed by Borsai et al. in 2021, the main aim was to prepare an effective method for in vitro propagation of *Aronia* and to set up a new wave to produce valued plant material. Shoot tips and nodal stem parts were taken from one-year-old shoots and used as the initial explants for in vitro culture in MS medium supplemented with 0.5 mg/L 6-BA. Initiation was made with a percentage of 47%. Basal media utilized for the propagation stage: MS medium, DKW medium (Driver and Kuniyuki Walnut), and WPM medium (woody plant) including plant growth regulators with different concentrations. Microplants were acclimated to peat–perlite (1:1; v:v) substrate and 90% success rate achieved [31]. In the study performed by Celebi-Toprak and Alan in 2020, nodal explants were made ready originating at shoots grown in vitro for rooting and R1 (WPM enriched with 1 mg per liter IBA) and R2 (half-strength WPM supplemented with 3 mg per liter IBA). Most of the explants generated roots and shoots on the rooting medium in 3 months. All 3 varieties were completely propagated with minor variations [32].

3. Characteristic Composition of Black Chokeberries

Fresh fruits typically have an astringent and bitter taste, and *Aronia* has gained significant popularity in recent years as one of the most researched berry species for dietary supplements. *Aronia* berries are renowned for their rich content of health-promoting bioactive compounds, including polyphenols, vitamins, and minerals [6, 17–19]. Thanks to their abundance of secondary metabolites contributing to overall health and well-being, *A. melanocarpa* berries have earned the title of “superberry” [20, 21].

To fully assess the health implications, it is crucial to analyze the detailed composition, including specific compounds and nutrients, of black chokeberries. These berries, with their high polyphenolic content including anthocyanins, flavonoids, and various phenolic acids, are well-known for their antioxidant capabilities. Black chokeberries also include important minerals, including potassium and manganese, and are a large source of vitamin C, which is necessary for immunological function. Researchers have identified approximately 8000 different polyphenolic chemicals within the plant kingdom. Notably, black chokeberries stand out among various berries for hosting the highest concentration of these polyphenols [33, 34]. Polyphenols, recognized as important secondary metabolites in plants, are synthesized using shikimic acid or phenylalanine as precursors. These compounds have either one or several hydroxyl groups on aromatic rings and exhibit diverse conjugated forms, including attachments to sugar residues, carboxylic acids, amines, lipids, organic acids, and other phenols [35–37].

Based on the quantity of phenol rings along with the additional structural components present, polyphenols are classified into four primary groups: phenolic acids, flavonoids, stilbenes, and lignans [33, 36, 38]. In plants, polyphenols play crucial roles in various physiological processes, including lignification, pollination, pathogen resistance, UV radiation protection, and growth. Moreover, these compounds are responsible for the vivid hues of fruits, vegetables, tea, wine, and other plant-based foods [39, 40]. In human dietary contexts, polyphenols are believed to offer a multitude of health benefits. These include antioxidant effects, anti-inflammatory properties, improvements in lipid profiles, prevention of insulin resistance, and potential contributions to cardiovascular health [41–43].

3.1. Phenolic Acids. Plants contain a class of chemicals called phenolic acids, which are well-known for their antioxidant qualities. They belong to the class of secondary metabolites called phenolic compounds, which are produced by plants [44, 45]. They play diverse roles in plant symbiotic interactions with soil microbes, functioning as signaling molecules [46, 47]. They are also crucial for seed germination, seedling growth, and protecting plants from pathogens and insects [48]. Additionally, phenolic acids contribute to the astringent flavor of black chokeberries [49]. Benzoic acid derivatives are generally scarce in edible plants, excluding red fruits, whereas phenolic acids derived from cinnamic acid are more prevalent in black chokeberries. In *Aronia* berries, chlorogenic and neochlorogenic acids (Figure 3) are the most abundant forms of hydroxycinnamic acid, collectively constituting approximately 7.5% of *Aronia*'s polyphenol content [18, 50].

Due to their higher water solubility, chlorogenic and neochlorogenic acids are predominantly found in the juice of *Aronia* berries compared to their concentrations in the fresh and dry weights of the fruit, pomace, and juice [18, 51–53]. For instance, Oszmiański et al. [18] reported that the concentration of chlorogenic acid in fruit juice is 415.86 mg/100 g and of neochlorogenic acid is 393.10 mg/100 g, whereas in the pomace and fruit, the concentrations are 301.85 mg/100 g and 204.81 mg/100 g for chlorogenic acid, and 169.20 mg/100 g and 290.81 mg/100 g for neochlorogenic acid, respectively [18]. Similarly, Rodríguez-Werner et al. found 414 mg/100 g of chlorogenic acid and 490 mg/100 g of neochlorogenic acid in *A. melanocarpa* juice. These findings suggest a notably higher concentration of chlorogenic and neochlorogenic acids in fruit juice compared to their levels in the dry weight (pomace and fruit) of black chokeberries. The slight differences reported by different studies may be affected by factors such as cultivar differences, harvesting times, or analytical methods used [51].

In 2010, Pop et al. conducted an analysis of polyphenols and antioxidant contents in five distinct cultivars of black chokeberries (Viking, Nero, Fertödi, Hugin, and Aron). Their findings were consistent with previous research by Oszmiański et al. [18] and Rodríguez-Werner et al. [51], indicating chlorogenic content as the predominant constituent in terms of fresh weight across all cultivars of *A. melanocarpa*. Among these cultivars, Viking exhibited the highest phenolic acid content, with chlorogenic acid measured at 1960.72 mg/kg and neochlorogenic acid at 1156.59 mg/kg. Similarly, Nero demonstrated comparable results, with 1931.45 mg/kg of chlorogenic acid and 1057.00 mg/kg of neochlorogenic acid. In contrast, the Aron cultivar displayed the lowest phenolic acid content, recording chlorogenic acid at 1254.20 mg/kg and neochlorogenic acid at 883.31 mg/kg.

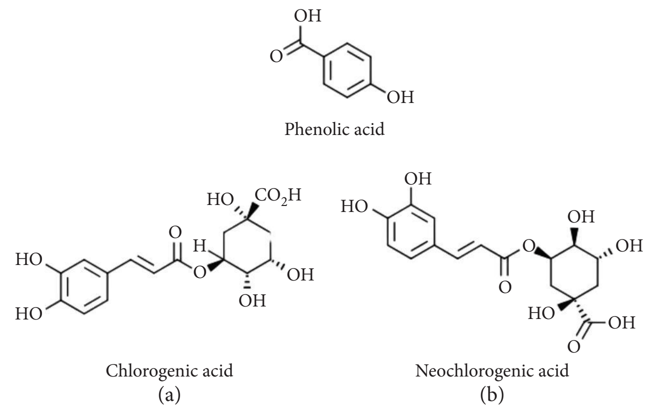

Figure 3: Chemical structure of phenolic acid. Chlorogenic acid (a), neochlorogenic acid (b) [44, 45].

Bolling et al. conducted a study on phytochemical changes in black chokeberry juice over 7 weeks of harvest, focusing on the Viking cultivar. Their findings revealed intriguing patterns. The juice extracted from freshly harvested berries in the first week of ripening exhibited the highest hydroxycinnamic acid content. However, as subsequent weeks progressed, there was a noticeable decline in the levels of hydroxycinnamic acids in the juice. This observation suggests that the hydroxycinnamic acid content, including compounds like chlorogenic and neochlorogenic acids, peaks at the initial harvest but progressively decreases in the following weeks. Such temporal changes in polyphenol levels could be influenced by various factors such as ripening stages or storage conditions occurring in the berries postharvest [54].

3.2. Flavonoids. Flavonoids, recognized as secondary metabolites within plant structures such as fruits and seeds, play pivotal roles by providing color, taste, and aroma. Their antioxidant properties contribute to several health-promoting effects in humans, including anti-inflammatory, cardio- and neuroprotective effects, anticancer properties, and potential antiaging benefits [36, 52, 55]. This diverse group of compounds comprises six primary subclasses: flavonols, flavanones, flavones, isoflavones, and anthocyanins. In black chokeberries, the most prevalent flavonoids include anthocyanins, proanthocyanidins, and flavanols (Figure 4) [17, 50].

3.2.1. Anthocyanins. Anthocyanins are water-soluble pigments that belong to the flavonoid class of compounds found in plants and significantly contribute to the vibrant hues observed in plants [56–58].

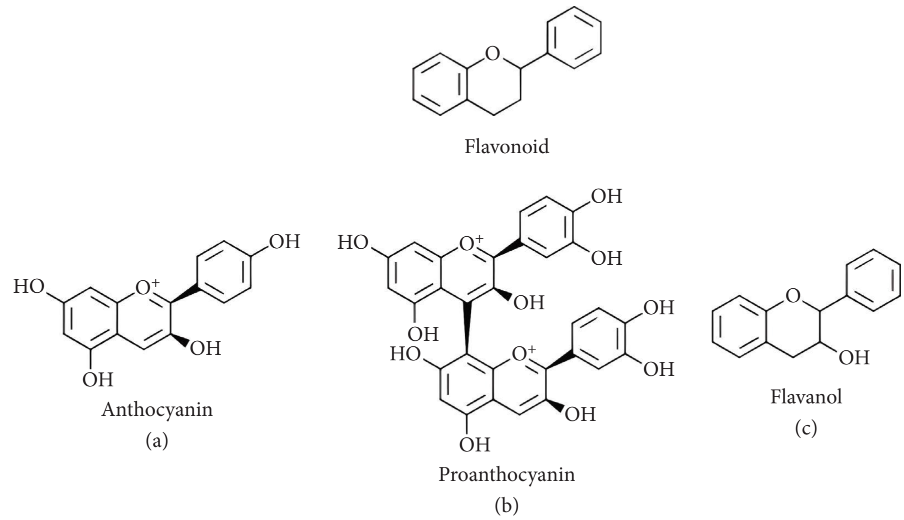

Figure 4: Chemical structure of flavonoids. Anthocyanin (a), proanthocyanidin (b), and flavanol (c) [17, 50].

Anthocyanins represent 25% of the total phenolic content within black chokeberries [18]. Several research studies have aimed to analyze the sorts and concentrations of anthocyanins present in *A. melanocarpa* berries, identifying four principal cyanidins: cyanidin-3-galactoside, cyanidin-3-glucoside, cyanidin-3-arabinoside, and cyanidin-3-xyloside (Figure 5) [18, 21, 59–61]. Among them, cyanidin-3-galactoside emerges with the highest recorded content, boasting 1284 mg/100 g in dry weight [18] and 990 mg/100 mg in fresh weight [62]. This compound was abundant in fruit juice, with concentrations of 1817 mg/L [59] and 787 mg/L [18]. Regarding the relationship between harvest time and polyphenol content, Bolling et al. [54] suggest a rise in anthocyanin levels until the fifth week of harvest. Furthermore, Taheri et al. [][][63] conducted a study involving 12 different accessions of *Aronia* berries varying in color (3 red, 4 purple, and 5 black chokeberry accessions), revealing that the maximum quantities of anthocyanins were present in black chokeberries, with levels reducing as the berries transitioned from purple to red [54].

3.2.2. Flavonols. Black chokeberries contain a comparatively low amount of flavonols, comprising only 1.3% of their composition [18, 64]. Three common quercetin derivatives have been identified in black chokeberries: quercetin-3-rutinoside, quercetin-3-galactoside, and quercetin-3-glucoside (Figure 6). The most abundant quercetin derivative, quercetin-3-galactoside, records concentrations of 36.98 mg/100 g in dry weight [18] and 30.2 mg/100 g in fresh weight [61].

While no correlation has been established between flavonols and fruit color [63], reports on flavonol content concerning harvest time show variability, with the highest levels typically observed during the early stages of ripening [54].

3.2.3. Proanthocyanidins. Plant proanthocyanidins, which are also called condensed tannins, are mostly present in seeds and stems in plants and serving as defense against herbivores and pathogens. Among berry species, chokeberries exhibit the highest levels of proanthocyanidins, constituting approximately 66% of the total fruit polyphenols in *A. melanocarpa* berries [18, 67]. Proanthocyanidin content is notably high, measuring 5182 mg/100 g in dry weight [18] and 1740 mg/100 g in fresh weight [55]. Additionally, Bolling et al. observed an increase in proanthocyanidins across each ripening stage of *Aronia* berries [54].

3.3. Dietary Fibers. Dietary fibers, including plant oligosaccharides, polysaccharides, lignin, and associated substances, resist digestion by human enzymes, undergoing breakdown by gut bacteria into short-chain fatty acids, partially used by humans. These fibers are classified as soluble dietary fiber (SDF) or insoluble dietary fiber (IDF), with berries like chokeberry containing predominantly IDF [68–71].

The polyphenol and dietary fiber content of various berry species, including blackcurrant, redcurrant, gooseberry, rowanberry, and chokeberry, were elucidated [72, 73]. Across all berry species examined, the most abundant type of dietary fiber was identified as IDF. *A. melanocarpa*, commonly known as chokeberry, exhibited moderate levels of dietary fiber, with IDF constituting the predominant type. Reißner et al. reported 524.6 g/kg of IDF and 70.4 g/kg of SDF in the dry weight of pomace for *A. melanocarpa* [72]. Similarly, Schmid et al. found that *A. melanocarpa* fruit pomace contained 57.8 g/100 g of total dietary fiber in dry weight, with IDF being the predominant type at 43.8 g/100 g, accounting for 76% of the total dietary fiber content. Additionally, the pomace contained 11.5 g/100 g of high-molecular-weight SDFs and 2.4 g/100 g of low-molecular-weight SDFs [73].

3.4. Sugar. *A. melanocarpa* contains 4 major classes of sugar: glucose, fructose, sucrose, and sorbitol. In comprehensive research conducted by Denev et al. (2018), which

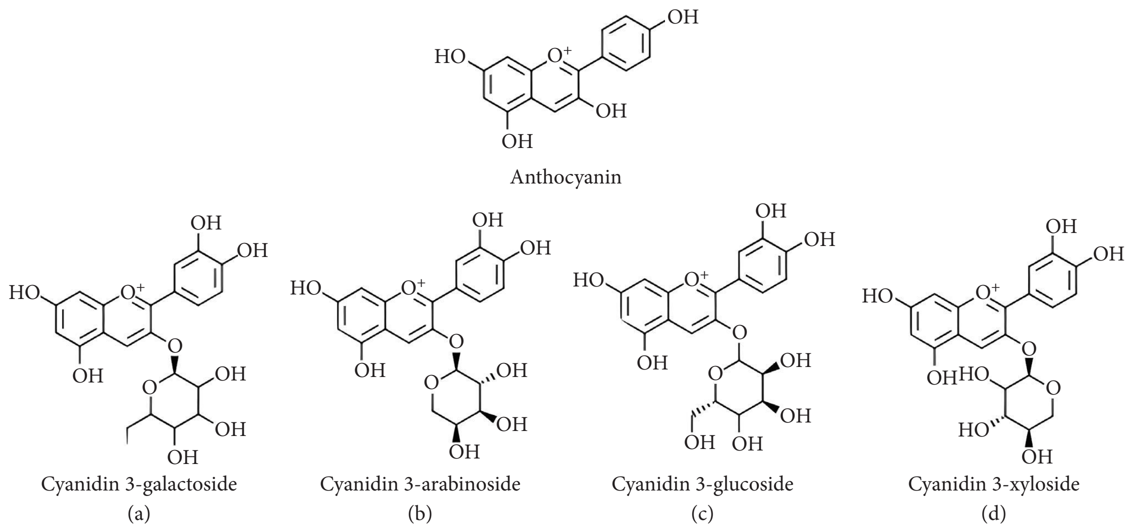

Figure 5: Chemical structure of anthocyanin. Cyanidin-3-galactoside (a), cyanidin-3-arabainoside (b), cyanidin-3-glucoside (c), and cyanidin-3-xyloside (d) [18, 21, 59–61].

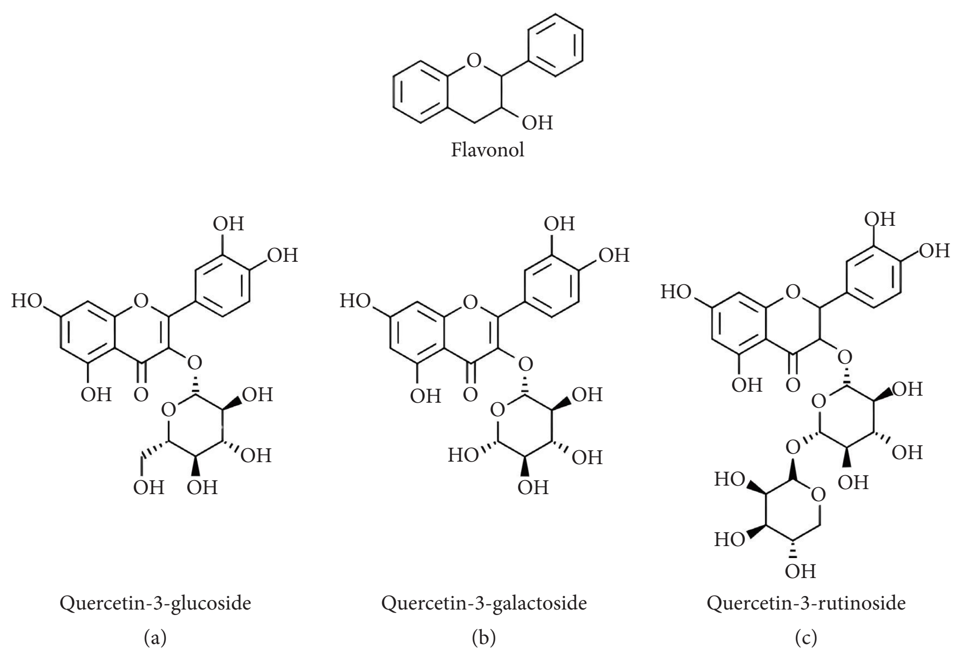

Figure 6: Chemical structures of flavonol. Quarcetin-3-glucoside (a), quarcetin-3-galactoside (b), and quarcetin-3-rutinoside (c) [65, 66].

investigated the sugar, organic acid, and polyphenol content of 23 different *Aronia* samples from the Nero variety, sorbitol was identified as the primary carbohydrate source in *Aronia* fruit, ranging from 6.6 to 13 g/100 g in fresh weight. Fructose ranged from 2.2 to 3.42 g/100 g, glucose varied between 1.53 and 3.02 g/100 g, and sucrose was the least abundant sugar, ranging from 0.06 to 0.33 g/100 g in fresh weight [74].

Mikulic-Petkovsek et al. conducted a comparative analysis of sugar, organic acids, and total phenolics content in 25 different berry species, where chokeberry stood out for having one of the highest total sugar contents, amounting to 618.9 g/kg in fresh weight. Additionally, chokeberry, alongside rowanberry and eastern shadbush, contained sorbitol, registering at 46.2 g/kg in fresh fruit [75].

Mayer-Miebach et al. analyzed commercial chokeberries, juice, and pomace to assess their total sugar and sugar alcohol content. The juice exhibited the highest total sugar content, ranging between 110 and 143 g/L. The identified sugar components included glucose, fructose, and sorbitol, with sorbitol registering as the highest in sugar content for the juice (between 47.8 and 63.8 g/kg), berries (between 43.6 and 76.1 g/kg), and pomace (37.6 g/kg) samples [76].

Moreover, Bolling et al. examined the changes in sugar content in *Aronia* berry juice over a 7-week ripening period in August–September 2012, revealing a proportional increase in sugar content corresponding to the ripening period. Glucose, fructose, and sorbitol were identified as the primary sugars in the juice, with sorbitol emerging as the predominant sugar content [54].

3.5. Lipids. Lipids, comprising fats (triglycerides), phospholipids, and steroids, are a diverse group of water-insoluble organic molecules [77].

Aronia seeds are particularly rich in linoleic acid and oleic acid [78, 79]. Linoleic acid (18:2 o-6) is a major plant lipid, characterized as an 18-carbon polyunsaturated omega-6 fatty acid. Conversely, oleic acid (18:1 o-9) is the most abundant monounsaturated fatty acid (MUFA), featuring an 18-carbon fatty acid chain with a single double bond located at the 9th carbon from the omega (methyl) end of the molecule [80]. *Aronia* seed oils also boast a rich content of phospholipids, sterols, and tocopherols [79].

In 1999, Zlatanov performed a comparative study of the lipid content of chokeberry (*A. melanocarpa* L), black currant (*Ribes nigrum* L), and rose hip (*Rosa canina* L) seeds. The total seed oil content of chokeberry was found to be 19.3 g/kg, with phospholipids, sterols, and tocopherols as the main components. Despite black currant having the highest seed oil content among the three berries, chokeberry exhibited the highest phospholipid content, with 2.8 g/kg in oil. The primary phospholipids identified were phosphatidylinositol (29.8 g/kg in fw), phosphatidylcholine (19.9 g/kg in fw), phosphatidylethanolamine (16.6 g/kg in fw), and phosphatidic acid (15.8 g/kg in fw). Furthermore, the most common fatty acids in chokeberry seed oil were linoleic acid (71.1 g/kg in wt) and oleic acid (21.4 g/kg in wt), findings consistent with those reported by Piasecka et al. [78]. Piasecka et al. analyzed the seed oil content of blackberry (*Rubus fruticosus*), chokeberry (*A. melanocarpa*), and raspberry (*Rubus idaeus*), revealing that the predominant fatty acid type in chokeberry was polyunsaturated fatty acids (PUFAs) at 73.79%, with linoleic acid accounting for 67.62% of these PUFAs. MUFAs constituted 18.21% of the total fatty acids, with oleic acid comprising 17.48% of the total MUFA [78].

Linoleic acid is the major component of total black chokeberry pomace lipids (64.67% (fatty acid/mass)), with chokeberry pomace containing the highest linoleic acid content compared to other berries such as wild blueberry (*Vaccinium myrtillus*), cultivated blueberry (*V. myrtillus*), wild cowberry (*Vaccinium vitis-idaea*), and raspberry (*R. idaeus*). The predominant fatty acid type in chokeberry pomace was PUFA at 65.01%. The total sterol content of chokeberry pomace is 148.22 mg/100 g, with β-sitosterol being the most abundant sterol at 74.42% of the total sterol content [81].

3.6. Proteins. *Aronia* berries have a low protein content, with 0.7 g/100 g fresh weight [82] and 3.71 g/100 g dry weight [83]. In *Aronia pomace*, the total protein content is reported to be 13.15% [84]. The total essential amino acid content in *A. pomace* is 28.90 g/kg dry weight, with glutamic acid (Glu) being the most abundant amino acid at 19.79 g/kg [85].

Various commercial *Aronia* juices were analyzed for their amino acid content, revealing an average total amino acid content of 102.33 μg/mL, with 42.83 μg/mL of the total amino acids being essential amino acids [86].

3.7. Organic Acids. Organic acids in plants are naturally occurring compounds that play essential roles in metabolism, growth, and stress responses, including citric acid, malic acid, and oxalic acid [87–90]. Mikulic-Petkovsek et al. revealed that chokeberry contains ascorbic acid, shikimic acid, citric acid, and tartaric acid, with a total organic acid content of 98.1 mmol/kg. Among these acids, shikimic acid is the most abundant in *Aronia* berries, with a content of 55.4 mmol/kg in fresh weight. Chokeberry, along with rowanberry and eastern shadbush, was found to have one of the lowest citric acid contents, with only 1.3 mmol/kg of citric acid [75].

In another study conducted by Denev et al. in 2018, seven significant organic acids were identified in *Aronia* fruit: quinic acid, malic acid, ascorbic acid, shikimic acid, citric acid, oxalic acid, and succinic acid. Quinic acid was found to be the most common organic acid in *Aronia* berries, averaging 404.4 mg/100 g in fresh weight. Ascorbic acid, contributing to *Aronia* berries' status as a good source of vitamin C, ranked as the third highest in concentration, with an average of 65.2 mg/100 g in fresh weight [74].

3.8. Vitamins and Minerals. In a study by Kim et al., which compared nine different fruit species for their vitamin C content, *Aronia* ranked second with an ascorbic acid content of 923.5 mg/L, following blueberries, which contained 969.9 mg/L in their commercial products [91]. Furthermore, Catana et al. conducted an analysis of vitamin C content in various forms of *A. melanocarpa*, including fresh, frozen, and dried fruits, as well as juice, jam, and compote in 2017. They reported the highest vitamin C content to be 31.85 mg/100 g in fresh fruit and 28.78 mg/100 g in frozen fruits [92]. Notably, the vitamin C content in fresh *Aronia* berries found by Catană et al. surpassed the values reported by Kulling and Rawel, 2008 (1.3–27 mg/100 g) [17], Karakashova et al. (17.52 mg/100 g) [93], and Lupascu and Sîrbu (12–12.8 mg/100 g) [94]. This result highlights *Aronia*'s exceptional richness in vitamin C compared to various other fruit species and previous studies.

Aronia is also rich in vitamin E content, particularly in dried pomace. Pieszka et al. [85] conducted a comparative analysis of the chemical content of apple, strawberry, black currant, chokeberry, and carrot, revealing that chokeberry has the highest α-tocopherol content at 152.3 mg/100 g. Another important nutrient in *Aronia* berries is vitamin A. Research on berries of *A. melanocarpa* cv. Nero showed that chokeberries contain 0.77 mg/kg of vitamin A [82].

Aronia berries, leaves, juices, and teas are also rich sources of macro and microelements, including potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), iron

(Fe), manganese (Mn), zinc (Zn), and selenium (Se). Among these, potassium is the most abundant macroelement, with concentrations of 3842 mg/kg in berries, 2623 mg/kg in leaves, 2123 mg/kg in juices, and 1477 mg/kg in teas. Iron is the most abundant microelement, with concentrations of 11.8 mg/kg in berries, 21.8 mg/kg in leaves, 14.7 mg/kg in juices, and 35.8 mg/kg in bagged teas [95]. These results are consistent with those reported by Juranović Cindrić et al., who found concentrations of 6790 mg/kg dw of K, 1212 mg/kg dw of Ca, and 669 mg/kg dw of Mg in berries [20]. Kaličanin et al. analyzed the mineral content of *Aronia* berries, dried pomaces, and juices and found similar results. They also noted that potassium is the most abundant macroelement in chokeberries, with concentrations of 5110 mg/kg in berries, 3820 mg/kg in dried pomace, and 3776 mg/kg in juices. Additionally, manganese is the most abundant microelement in berries, with concentrations of 18.7 mg/kg, while iron is the most abundant microelement in dried pomace, with a concentration of 21.8 mg/kg [96].

4. Health Benefits of Black Chokeberries

4.1. Antioxidant Activity. Fruits and berries are phenolic-rich plant materials. Phenolics have antioxidant abilities thanks to their redox properties, such as reducing agents, singlet oxygen quenchers, or hydrogen donors [18]. Polyphenols, including phenolic acids, anthocyanins, proanthocyanidins, and flavonols, are abundant in chokeberry fruits [12]. These phenolic acids are mainly responsible for antioxidant activity. In recent years, numerous studies have explored the antioxidant properties of *Aronia* berries and their main phenolic components. These natural compounds suppress the activity of various types of radicals through diverse mechanisms, supporting additional bioactivities [97].

Using the oxygen radical absorption capacity assay, researchers compared the antioxidant activity of acetone extracts from black chokeberries, blueberries (*Vaccinium corymbosum*), cranberries (*Vaccinium macrocarpon*), and lingonberries (*Vaccinium vitisidaea*). The study revealed that black chokeberry extracts exhibited higher antioxidant activity compared to other samples [61]. After the oxygen radical absorbing capacity-based study was expanded to include other berries, *A. melanocarpa* was found to be the most powerful antioxidant among the mentioned berries, including gooseberry (*R. grossularia*), red currant (*R. rubrum*), black currant (*Ribes nigrum*), and elderberry (*Sambucus nigra*) [62].

Anthocyanins can scavenge various reactive oxygen species (ROS) or stimulate the expression of enzymes that rely on antioxidant response components, such as glutathione peroxidase (GPX), catalase (CAT), and superoxide dismutase (SOD) [98]. Thus, chokeberry, rich in anthocyanins, stands out with its health-promoting properties. In recent years, chokeberries have been the subject of many scientific studies due to their beneficial contributions to human health. *Aronia* can be incorporated into the human diet in various ways, including consuming fresh fruits, drinking fruit juice, enjoying jam or jelly, drinking tea, and using it as a food supplement.

Jakobek et al. determined the amounts of total polyphenol and total anthocyanin in berries of *Aronia* (*A. melanocarpa*), blackberry (*R. fruticosus*), red raspberry (*R. idaeus*), and strawberry (*Fragaria ananassa*) from methanol-HCl extracts. 5–20 g of grinding berries was used for analysis. 5–20 g of grinding berries was used for analysis. According to the results, the most and least total polyphenols and anthocyanins were detected in *Aronia* and strawberry, respectively. While the amount of total anthocyanins was 232–4341 mg kg^{-1} in strawberry and *Aronia*, respectively, the amount of total polyphenols was 1005–10,637 mg kg^{-1} [59]. In a study conducted with rats, it was determined that a commercial *Aronia* extract, which contains 0.612 ± 0.003 mg/mL total polyphenols, was effective in reducing oxidative stress caused by cadmium. 1 and 5 mg of Cd/kg containing diet had a protective effect against organ damage by increasing the antioxidative barrier in the liver [99]. Additionally, in another study conducted with the fruit fly *Drosophila melanogaster*, 2.5 mg/mL *Aronia* extract prepared with acetone increased SOD, CAT, and GPX activities; decreased ROS, lipid oxidation, and stress resistance gene expression; and extended mean lifespan by 18% [100].

In addition to berries and extracts, *Aronia* juice also has very high antioxidant activity [101]. In a 3-month study conducted with overweight and healthy people, it was observed that 150 mL commercial black chokeberry juice consumed daily increased SOD and CAT activities. SOD enzyme activity was increased from 0.046 ± 0.010 to 0.071 ± 012 U/mL, and CAT enzyme activity was less pronounced. Also, the juice decreased the thiobarbituric acid–reactive substance from 32.85 ± 2.16 to 23.24 ± 2.62 nmol/mL and C-reactive protein concentrations from 4.1 ± 1.1 to 3.06 ± 0.76 mg/L in the serum of the overweight group [102]. Besides, in fission yeast, *Schizosaccharomyces pombe*, black chokeberry juice, including 4.91 mg/g total polyphenols, reduced the toxicity of acrylamide by enhancing antioxidant cell capacity and metabolic activity due to its potent ROS scavenging ability [103]. Therefore, chokeberry juices might be a good supply of bioactive phytochemicals in the human diet. Also, in comparison to the majority of regularly consumed berry teas, black chokeberry fruit teas were discovered to be a valuable source of flavonoids and anthocyanins [104].

Aronia is also consumed as a supplement. Two months of 300-mg chokeberry extract administration, including 3-O-cyanidin-glucoside (2.4%), 3-O-cyanidin-galactoside (64.5%), 3-O-cyanidin-xyloside (4.2%) and 3-O-cyanidin-arabinoside (28.9%), significantly reduced total and low-density lipoprotein cholesterol from 158.71 ± 35.78 to 146.21 ± 34.63 mg/dL, systolic blood pressure from 143.40 ± 7.87 to 131.83 ± 12.24 mmHg, diastolic blood pressure from 87.20 ± 9.90 to 82.13 ± 10.33 mmHg, and triglyceride levels from 215.92 ± 63.61 to 187.58 ± 90.00 mg/dL in patients with metabolic syndrome in concordance with SOD and GPX increase [98]. Additionally, daily use of commercial chokeberry supplement capsules for 6 weeks approximately 3 months significantly reduced systolic and diastolic blood pressure by 11.0 and 7.2 mmHg, respectively, and this effect was not observed in the placebo group.

Besides, oxidized low-density lipoprotein levels were decreased from 91.6 ± 26.9 to 67.7 ± 24.7 u/L [105]. Another study focusing on the usage of chokeberry extracts on 143 metabolic syndrome patients (age 50–60) revealed that four weeks of commercial chokeberry extract, including 431 mg/30 mL polyphenols and 120 mg/30 mL anthocyanins, consumption decreased low-density lipoprotein from 3.77 to 3.36 mmol/L, total serum cholesterol from 6.16 to 5.56 mmol/L, systolic blood pressure from 139.72 to 126.16 mmHg, diastolic blood pressure from 85.67 to 78.53 mmHg, and white blood cells from 8.9 to 7.0 10^9 cells/L for male patients, and similar significant decreases were also recorded for female patients with metabolic syndrome [106].

In general, the antioxidant qualities of *Aronia* berries hold promise for improving human health and protecting against various illnesses. Therefore, it is crucial to comprehend the function of *A. melanocarpa* components and byproducts in human nutrition and how they affect human health. The burgeoning black chokeberry and its derivatives demonstrate that they have potential value in the food industry as an antioxidant source.

4.2. Antimicrobial Effects. Much like their antioxidative properties, phenolic compounds serve as the basis for the antibacterial activity observed in plant extracts [49]. The presence of carboxyl groups and the configuration of substitutions on the benzene ring are the primary factors determining the efficiency of phenolic acids as antibacterial agents, according to Alves et al. [][][107]. Research has indicated that the quantity of hydroxyl groups within phenolic compounds might impact their antibacterial activity, while the presence of sugar molecules in flavonols may reduce their efficacy in impeding microbial development [108].

The antibacterial activities of subcritical water extracts with sample to solvent ratio 1:20 made from *Aronia* leaves were examined by Cvetanović et al. [][][109] against two Gram-positive and four Gram-negative bacterial strains. The extract's capacity to inhibit fungal activity against two different fungal species was also assessed. Amracin, a tetracycline antibiotic, and *Aronia* extracts' antibacterial effectiveness were compared by the researchers. In comparison to amracin, they found that the leaf extracts' antibacterial efficacy was four times higher against *P. vulgaris* and fifteen times stronger against *Proteus mirabilis*. Deng et al. applied the compound *A. melanocarpa* anthocyanins (AMAs) with bactericidal activity at various concentrations on *Escherichia coli* (*E. coli*) suspension. In the study, 500 g of *A. melanocarpa* samples was used for ultrasonic-assisted extraction with 75½ ethanol. This extraction was performed for producing anthocyanin extract of *A. melanocarpa*. 0.156, 0.313, 0.625, 1.25, 2.5, 5.0, and 10 mg/mL were the final concentrations of the AMAs. According to the study's findings, as the concentration of AMAs increased, the *E. coli* bacteria entered a bacterial growth curve, completely inhibiting their growth. The release of cellular components was interpreted as potential disruption and destruction in the bacterial cell walls and membranes based on scanning and transmission electron microscopy analyses. Furthermore, based on the SDS-PAGE analysis conducted, the absence of protein bands might be attributed to the penetration of AMAs into the bacterial cells [110].

The antibacterial characteristics of *A. melanocarpa* fruit were investigated in a study by Liepina et al. [111]. Within this study, two distinct extracts (aqueous and ethanolic) derived from fruits were used as either fresh, dried, or frozen. The *A. melanocarpa* extracts from fresh material were obtained from 227-g weighed black chokeberry. This material was ground in a mortar with a pestle. Then, these samples mixed with 100 mL of sterile distilled water for aqueous extracts or 50% ethanol for ethanolic extracts. For obtaining dried extracts, fresh material fruit was dried in an automatic dryer, and 10 g of the dried material was mixed with 40 mL of water for aqueous extracts or 50% ethanol for ethanolic extracts. Then, dulcified samples were ground in a mortar and again mixed with additional same amount of water or ethanol. Finally, it is filtered through a muslin. Last extraction from frozen material was performed again from fresh material. These samples were left frozen at −20°C temperature within the closed tubes for 5.5 months. Subsequently, ethanolic and aqueous extracts were tested against both Gram-negative and Gram-positive bacteria. The antibacterial effect of ethanolic and aqueous extracts on *Bacillus* cereus, *Staphylococcus aureus* (Gram-positive bacteria), and *Pseudomonas aeruginosa* (Gram-negative bacteria) was evaluated, and it was interpreted that ethanolic extracts were equal to or more effective than aqueous extracts [111]. Additionally, the process of drying the fruits to create extracts and subjecting these extracts to heat treatments such as autoclaving and freezing modified their antibacterial characteristics, either enhancing or diminishing their inhibitory effects. Extracts from fresh fruits displayed inhibition against all examined bacteria except *E. coli*. In contrast, extracts from dried or frozen fruits only exhibited inhibition against Gram-positive bacteria. Consequently, freezing the fruits resulted in a decline in their antibacterial efficacy. Extracts that were either autoclaved and frozen from fresh fruits demonstrated equivalent or greater antibacterial properties compared to fresh extracts. However, freezing extracts derived from dried fruits diminished their antibacterial efficacy, with frozen fruit extracts showing little antibacterial activity. In another research study by Kim et al., ethanol extraction was performed from dried powder of *A. melanocarpa* samples. These samples were dulcified in 95% ethanol for 48 h, and the soluble ingredients of the mixed samples were evaporated to obtain stock ethanol extract. The ethanol extract of crude *A. melanocarpa* was tested against the same bacteria, *B. cereus*, and *S. aureus* [91]. According to the results of the study, the ethanol extract tested by spot-on-lawn test showed various levels of antibacterial activity. It was also shown that the inhibitory activity of the ethanol extract was independent of the concentration excess.

The antimicrobial properties of *A. melanocarpa* fruits, rich in polyphenolic hydroxyl groups [112], have been studied in more than one bacterial species [91, 113]. However, meat and meat products are susceptible to microbial spoilage that can cause serious health problems for consumers. Tamkutė et al. [114] evaluated the antimicrobial potential of freeze-dried, defatted *A. melanocarpa* pomace extracts in pork products and some microorganisms (*Leuconostoc mesenteroides* (*L. mesenteroides*), *Weissella viridescens, Brochothrix thermosphacta, Listeria monocytogenes, Campylobacter jejuni, and Pseudomonas putida*) culture. In this study, freeze-dried chokeberry pomace samples were ground and separated from the oil by supercritical CO_2 in a 10-L container as performed in the Grunovaite et al. study [115]. The defatted powder was mixed with diatomaceous earth in 50 mL of cells and extracted with ethanol at a pressure of 10.3 MPa. Then, the final residue was extracted again with water. The ethanol materials evaporated by rotary and water were removed with freeze-drying. The result of the evaluation proved antimicrobial activity and inhibition of the growth of all bacterial species except *W. viridescens* and *L. mesenteroides* [114]. In another similar study conducted by Daotidou et al., *A. melanocarpa* aqueous and ethanolic extracts were tested on *E. coli, Streptococcus pyogenes*, and *S. aureus* bacterial strains [116]. In the extraction method of study, *A. melanocarpa* beads were blended for 1 min; then, 10-g puree was mixed with 200 mL of each solvent (5% v/v). After that, the aqueous solutions were filtered and centrifuged, and then, the supernatants of the samples were evaporated. 2 g/mL concentrated solution was obtained, and 5 mL distilled water was added on it. All tested extract concentrations were 62.5, 25, 250, 500, and 1000 mg/mL. According to the results of the study, the inhibition zone of aqueous extracts was larger than that of ethanolic extracts.

Research especially indicates that extracts from *A. melanocarpa* possess antimicrobial activity, with phenolic compounds playing a key role in this effect. A study conducted by Park et al. demonstrated that *A. melanocarpa* ethanolic extract has an antiviral activity because of its polyphenol and flavonoid contents. Even 0.0625 mg samples isolated from *A. melanocarpa* by ethanol extraction exhibited high anti-influenza activity and were inhibited virus surface proteins with 70% of influenza viruses (H1 and H3) [117]. Additionally, increasing the concentration of A. melanocarpa to 0.125 mg resulted in more than 60% efficacy against all tested viruses. This suggest that *Aronia melanocarpa* hold broad antiviral role against influenza viruses.

Another study was performed by Ochnik et al. [118] and is about antiviral activity of double-standardized extract of *A. melanocarpa* against human respiratory influenza A virus (IAV) (A/H1N1) and human betacoronavirus-1 (HCoV-OC43). In this study, frozen *A. melanocarpa were* extracted with water and the extraction of the samples was carried out using the percolation method, and then, the resulting mixture was filtered. The drug/extract ratio for *A. melanocarpa* was determined as 70:1. With an anthocyanin concentration of 566.6 mg/mL, more than 700 L of *A. melanocarpa* extract was loaded onto the chromatography column to obtain 400 g of anthocyanins. 75% of ethanol was used to elute the absorbed compounds. After that, 25% of the dry weight of the main compound was dried in a spray dryer. According to the result of the study, these extracts demonstrated the highest antiviral activity against human A/H1N1 and HCoV-OC43 viruses. Doble-standardized extracts of *A. melanocarpa* inhibited with 72% the replication of human influenza viruses.

A research article conducted by Eggers et al. [119] demonstrated *A. melanocarpa* juices that are purchased directly from manufacturers have antiviral activity against EBOV, SARS-CoV-1, MERS-CoV, and SARS-CoV-2. In this study, stains of these viruses were incubated in *A. melanocarpa* juices in 5 min. Then, it was shown to decrease the infectivity with 99.99% of these viruses. Furthermore, another study conducted by Frank et al. was realized with the same purpose [120]. The severe acute respiratory SARS-CoV-2 and IAV were inhibited by the *A. melanocarpa* juices.

A different study is about the antiviral role of *A. melanocarpa* extracts (AEs) combined with carrageenan (ACNC), which is a stabilizing molecule [121]. Both AE and CGN were obtained from another lab. 20-mg AE was dissolved in phosphate buffer pH 3 at 40°C, and 80 mg of CGN was dissolved in deionized water at 60°C. After that for preparation of AE and CGN solutions, mix in a 1:4 weight ratio, with sample concentration of 2 mg/mL. In this mice study, ACNC was used against influenza A/California/07/2009 (H1N1) virus that originally obtained from the influenza H1N1 virus was acquired from the Korea Centers. According to the result of the study, plaque formation that occurred because of virus infection inhibited 100 percent after treatment with ACNC. Therefore, this study demonstrates the intranasal administration of ACNC has an antiviral role on H1N1 virus.

However, further investigation of existing data and diversification of studies on different microorganisms are needed. These studies can help us better understand the potential benefits of *A. melanocarpa* in terms of its antimicrobial properties.

4.3. Anticancer Effects. Some epidemiological studies suggest that a diet rich in antioxidant-rich fruits can lower the risk of cancer, implying that dietary antioxidants might be effective in cancer prevention. *Aronia* fruit, based on studies, has shown promise as a dietary supplement in cancer cases [64]. Furthermore, compared to other berry crops, the polyphenolic extract of black chokeberry fruit has been shown to have a chemopreventive effect through a variety of mechanisms, including changes in cellular signaling, induction of detoxification enzymes, reduction of oxidative stress, promote of cell cycle arrest, apoptosis, support of the immune system, and prevention of oxidation [122]. Even if a significant amount of the phenolics in chokeberries change during digestion, Stanisavljević et al. showed that these compounds are still effective as antiproliferative and antioxidants. The study examined the impact of the chokeberry juice which is obtained from crushed and pressed fruits by a wine horizontal screw press, on the proliferation of Caco-2 cells, resulting in a reduction in the proliferative rate by around 25% [123].

According to Malik et al., human colon cancer cells showed significant growth suppression when exposed to *Aronia* extract. In the study method, 10 g of powdered anthocyanin-rich extract was dissolved in 100 mL of HCL (concentrated 0.01%). Then, the extract was pretreated with 100 percent ethanol with HCL and solid-phase semipurification. Blockages at the G1/G0 and G2/M phases of the cell cycle were observed in the treated cells [124]. The potential chemopreventive efficacy of chokeberry extract against colon cancer was also examined in research by Zhao et al. Both colon cancer-derived and nontumorigenic colonic cells displayed distinct growth patterns when exposed to various concentrations of *Aronia* extract. According to study, semipurification of anthocyanin extract was performed with C18 cartridge. 1 g of anthocyanin extract dissolved in the 10 mL of deionized water and then placed into the C18. Like the previous procedure of Malik et al. 2003 study, semipurification is completed. Specifically, when exposed to a certain concentration of the extract for a specific duration, colon cancer cell proliferation was significantly inhibited [125].

Rugină et al. investigated the anticancer potential of polyphenolic fractions from *A. prunifolia* and the cultivars Viking and Aron of *A. melanocarpa*. Both compounds, with and without anthocyanins, were isolated. The findings of the experiment demonstrated that, after 48 h of treatment, cyanidin glycosides markedly reduced the proliferation of HeLa human cervical carcinoma cells and increased the production of ROS [126]. The anticancer efficacy of the extract was influenced by the extraction process. In comparison to 50% methanol and hot water extracts, the 50% ethanol extract significantly inhibited the development of cancer cells in the HeLa cell line [127].

Sharif et al.'s study has shown that the *A. melanocarpa* juice consumption induced apoptosis, a form of programmed cell death, and reduced cell proliferation. Furthermore, it was observed that the juice caused cell cycle arrest specifically in the G(2)/M phase [128]. Aqueous acetone was used in a study by Sueiro et al. to extract the fruits of black chokeberries. To determine each genotype's potential as a cancer chemopreventive agent, the extract, certain fractions, and subfractions were evaluated using a human DNA catalytic topoisomerase II assay and a murine leukemia cell assay. The experiment's findings demonstrated that the black chokeberry's anthocyanin extract prevented human granulocytes from producing and releasing superoxide radicals. It has been reported that subfractions obtained from wild *Aronia* berries effectively inhibit leukemia cells when consumed at specific concentrations [129]. Research conducted by Sidor et al. indicates that water-based solutions derived from extracts of black chokeberry and strawberry effectively prevented the development of lung adenomas, liver degradation, and pulmonary emphysema induced by cigarette smoke, which is known to contain elevated levels of carcinogenic chemicals [130, 131].

The constituents of *Aronia* fruits, particularly the primary phenolic compounds identified in clinical trials, suggest promising potential for the development of novel anticancer medications, as previously discussed.

4.4. Antimutagenic Effects. Black chokeberries exhibit antimutagenic properties in vitro due to their anthocyanin content. The ability of anthocyanins to inhibit enzymes responsible for promutagen activation, as well as their capacity to scavenge free radicals, is attributed to them [132, 133]. Results of the Ames test showed that benzo-2-aminofluorene's carcinogenic qualities are eliminated by anthocyanins that are derived from chokeberry plants. Additionally, the sister chromatid exchange assay highlighted the significant antimutagenic action of AEs using human blood-derived lymphocytes grown in vitro for the assay. Benzo[a]pyrene and mitomycin C showed a 30% and 10% reduction in genotoxicity, respectively, as a result of the high anthocyanin concentrations. The phenolic components of black chokeberries are also responsible for their enhanced antimutagenic activity [132].

Additionally, administration of aminopyrine, sodium nitrite, and black chokeberry juice to male rats resulted in a reduction in the synthesis of naturally occurring N-nitrosamines. Consequently, histopathological alterations induced by nitrosamine precursors were observed in the livers of the mice, but coadministration of black chokeberry juice appeared to alleviate this effect [134]. In an additional investigation, *Aronia* fruit demonstrated a radioprotective impact by raising the survival rate of rats subjected to beta radiation and an antimutagenic effect by diminishing the debilitating effects of certain chemical mutagen compounds [135].

4.5. Antidiabetic Effects. Studies have indicated that the anthocyanins present in *A. melanocarpa* may have advantages in the treatment and prevention of Type 2 diabetes (T2D) as well as its aftereffects [136, 137]. *Aronia* fruit juice appeared to lower hyperglycemia and hypertriglyceridemia in diabetic rats in experimental research [136].

In a group of male Wistar rats weighing approximately 200 g, an ethanol extract of *Aronia* berries (100 mg/kg) gavage daily for eight weeks significantly reduced the levels of blood glucose, serum insulin, and insulin resistance while increasing the amount of glucose tolerance and hepatic glycogen in the organism [138]. Thirty-five individuals with T2D who were on regular diabetic care were given the phenol-rich *Aronia* juice (150 mL, three times a day, 50 mL each time) as part of an open-label trial. The fact that the patients' health improved suggests that *Aronia* juice could be a useful therapy or preventive measure for diabetes mellitus [139].

It is interesting to note that *Aronia* berries have demonstrated some positive effects when it comes to Type 1 diabetes treatment (T1D) [140]. Unlike T2D, which is caused by inadequate insulin usage, T1D is caused by an autoimmune reaction that destroys pancreatic cells, hence compromising insulin production. As a result, T1D is insulin-dependent and associated with significant organ failure because of high blood glucose. Streptozotocin (STZ) injection of six-week-old ICR-healthy male mice resulted in lower blood glucose levels and preserved mouse pancreatic cells in an animal model of T1D. The mice were given a single dose of 80 mg/kg of STZ intraperitoneally (i.p.) and were given an ethanol extract of *Aronia* berries (10 or 100 mg/kg) every day for thirty-one days. These findings suggest that consuming *Aronia* berries may help prevent pancreatic cancer and treat T1D [140].

Following a 3-month regimen of 200 mL of *Aronia* juice daily, patients with non–insulin-dependent diabetes showed lower fasting glucose levels in a human intervention study. Additionally, *Aronia* juice demonstrated a positive impact on total cholesterol, lipid levels, and HbA1c-glycosylated hemoglobin [137]. These findings align with studies illustrating the impact of other foods high in procyanidin on diabetes [141]. Recent human research has also suggested potential benefits of *Aronia* juice in the treatment of obesity issues [17].

4.6. Anti-Inflammatory Effects. It is known that extracts from chokeberries prevent the secretion of interleukin-6 induced by lipopolysaccharides (LPSs) and promote the excretion of interleukin-10 in splenocytes in nonstimulated conditions [142]. In an in vivo study assessing the anti-inflammatory properties of black chokeberries (100 mL of juice from approximately 1 kg of black chokeberries), the juice from *A. melanocarpa* notably alleviated the severity of swollen paws (10 mL of chokeberry juice per 100 g of body weight) caused by the introduction of histamine or serotonin solutions [143].

Separately, in an in vivo study conducted by Ohgami et al., the significant anti-inflammatory potential of intravenously administered black chokeberry extract was demonstrated in rats with endotoxin-induced uveitis, and 100 mg of black chokeberry extract showed a significantly robust effect [144]. Additionally, this study used the mouse macrophage cell line RAW 264.7 to offer a hypothesis, suggesting that the suppression of prostaglandin, TNF-α, and nitric oxide (NO) may be linked to the antiocular inflammatory effect of black chokeberry extract. It is believed that the reduction of cyclooxygenase-2 and inducible NO synthase production is what causes this inhibitory condition [144].

Additionally, involving the RAW 264.7 cell line, the anti-inflammatory effect of *A. melanocarpa* leaves was observed by Thi and Hwang [145]. The administration of berry leaf extract significantly decreased the levels of expression of TNF-α and interleukin-6 [145].

Using the reverse transcription polymerase chain reaction (RT-PCR) method, Downar and his colleagues examined the expression levels of TNF-α-induced molecules (ICAM-1 and VCAM-1) after administering AE [11]. Upon exposure to TNF-α, human aortic endothelial cells exhibited an elevation in the surface expression levels of ICAM-1 and VCAM-1 proteins. Meanwhile, under normal conditions, the expression levels were significantly low. However, when the cells were pretreated with an extract of *A. melanocarpa* (at 50 μg/mL) before the addition of TNF-α, there was a significant decrease in these expression levels. Specifically, ICAM-1 expression decreased by 35%, and VCAM-1 expression decreased by up to 45% [11]. In addition, it can be asserted that the *A. melanocarpa* fruit extract is capable of intervening with the transcription of these particular genes because the chokeberry extract can lead to a reduction in the expressed levels of mRNA for these genes, as compared to normal conditions [11]. As part of a comprehensive treatment approach, patients who had suffered a heart attack were given chokeberry extract (3 × 85 mg/day of chokeberry flavonoid extract) in conjunction with their regular regimen, which involved routine statin therapy [105]. It was observed that patients who incorporated *Aronia* extracts into their diet alongside statins for 1.5 months experienced an increase in their adiponectin levels, which is associated with decreased endothelial inflammation.

In summary, the available evidence suggests that *A. melanocarpa* possesses significant anti-inflammatory properties. In both in vivo and in vitro experiments, chokeberry extract demonstrated effectiveness in reducing inflammation markers. Overall, these findings suggest that *A. melanocarpa* may serve as a valuable anti-inflammatory agent.

4.7. Hepatoprotective Effects. *Aronia* is notable for its potential hepatoprotective qualities in addition to its crucial applications. Research is still being done to determine the exact processes via *Aronia* may benefit liver health and how it might be used in functional foods that support liver health. In a study with rats, anthocyanins from chokeberries reduced the toxicity and buildup of cadmium in the liver and kidney of the animals when these components were fed to them [146]. This might provide evidence for the theory that anthocyanins can chelate metal ions, which could lessen the harm caused by cadmium. Remarkably, after acute exposure to carbon tetrachloride (CCl4), rats also showed signs of a hepatoprotective benefit from *Aronia* juice [147]. The production of extremely reactive trichloromethyl free radicals by cytochrome P450 is the basis for the liver cytotoxicity caused by CCl4. Lipid peroxidation, which results in cell death, is triggered by the interaction of the CCl3 radical with oxygen. The amount of malondialdehyde in rat liver and plasma decreased, indicating that *Aronia* juice successfully countered the rise in lipid peroxidation brought on by CCl4. This suggests that the observed protective effect of *Aronia* juice is likely due to its anthocyanins and/or other phenolic compounds' ability to scavenge free radicals [17, 147]. However, in a different experiment, rats were induced with CCl4 for 6 weeks, while being supplemented with silymarin and *Aronia* juice during the same period. Supplements decreased lipid peroxidation and enhanced the activity of antioxidant enzymes in the liver, according to the findings. However, it was reported that this effect was solely attributed to silymarin, with *Aronia* showing no significant effect [148]. In another study, mice were exposed to alcohol for 6 months to induce liver damage, followed by supplementation with commercial *A. melanocarpa* for 6 weeks. Results revealed that *A. melanocarpa* reduced liver damage and increased antioxidant activities. Additionally, it was reported that *A. melanocarpa* enhanced the activation of antioxidant enzymes through the erythroid 2-like 2 (Nrf2) protein pathway [149]. Based on these studies, further research is needed to observe the hepatoprotective properties.

4.8. Other Effects. Inflammatory bowel diseases (IBDs) are chronic illnesses of the digestive tract for which there is no known etiology. The two primary forms of Crohn's and ulcerative colitis are identified among them [130]. The health of mice with ulcerative colitis was improved by black chokeberry extract after they had treatment with dextran sodium sulfate (DSS). Rats with colitis treated with black chokeberry extract showed decreased levels of proinflammatory cytokines (TNF-α and IL-6), prostaglandin 2 (PGE2) in colon tissue, and epithelial cell and crypt colony lesions. There is a strong possibility that the effect on macrophages was related to the cytokines TNF-α and IL-6 decreasing. When LPS was used to activate peritoneal macrophages, the extract prevented the overexpression of TNF-α and IL-6. The formation of NO, which is responsible for inflammatory alterations in the intestine and has cytotoxic activity due to its reactivity with ROS, was decreased when macrophages were preincubated with extract [150].

Additionally, black chokeberry shows a lot of promise for treating and preventing influenza [151]. Black chokeberry alcoholic extract suppressed the growth of many influenza virus strains, including ones resistant to the antiviral medication oseltamivir, depending on the concentration. Over 60% of the viral strains were unable to develop when exposed to black chokeberry extract. Hemagglutinin was primarily responsible for black chokeberry juice's ability to prevent influenza virus proliferation. Black chokeberry extract significantly reduced virus in the lungs and lowered mortality in influenza-infected mice [117].

The antioxidative properties of black chokeberry, as observed in the study by Skoczyñska et al., may affect proper erythrocyte function. The consumption of commercial black chokeberry juice also resulted in an increased share of PUFAs in erythrocyte membranes, indicating protection against oxidation. Similarly, PUFA concentration and antioxidative efficacy of erythrocytes were significantly increased in obese women who took 100 mL of commercial black chokeberry juice with glucomannan daily for 4 weeks. These findings suggest a link between the antioxidative properties of black chokeberry and improvements in erythrocyte function. Also, Kardum et al. have reported that the consumption of black chokeberry showed an important decrease in blood pressure [52, 152].

Based on these studies, it can be said that the increasingly popular consumption of black chokeberry may have therapeutic effects on chronic hypertension, cholesterol, etc., in addition to the previously mentioned effects (Table 1) [197, 198].

5. Black Chokeberries as a New Functional Food

Functional foods, which are defined by health advantages that go beyond the basics of nutrition, present difficulties for the traditional strategy of concentrating only on specific nutrients found in food. Consistently, epidemiological research has shown that a regular or higher fruit consumption is linked to improved general health and well-being as well as a lower risk of chronic illnesses. The wide range of bioactive substances, such as phytochemicals, antioxidants, vitamins, and minerals, that are present in fruits provides the scientific foundation for these health advantages [199].

There are a number of pathways linked to fruit consumption's possible health benefits. Fruits include antioxidants including polyphenols and flavonoids that help fight against inflammation and oxidative stress, two factors linked to the onset of chronic illnesses. Furthermore, fruits' high fiber content helps with blood sugar control, weight management, and better gastrointestinal health [200].

A vast amount of research is being done in the government, business, and academic sectors in order to answer the increased demand in utilizing fruits' health benefits. The purpose of this research is to discover certain bioactive chemicals found in fruits, comprehend their modes of action, and investigate novel ways to incorporate these compounds into meals that are typically consumed by consumers. The creation of innovative functional food products that provide and preserve the nutritional value of fruits in easily digestible forms is being made possible by developments in food science and technology [201].

Together with vitamins and minerals, the fruit and leaves of *A. melanocarpa* are a notable source of a wide variety of bioactive chemicals, primarily polyphenolic compounds. In the late 20th century, black chokeberries gained high value globally, primarily contributing to large-scale manufacturing of juices, jams, and wines while serving as a rich source of naturally occurring food coloring (Figure 7). The functional food sector has witnessed a surge in the popularity of black chokeberries due to the previously mentioned health benefits associated with this berry fruit [204]. Due to their bitter flavor, black chokeberries are seldom consumed fresh or uncooked. Instead, the small, black, cherry-like berries that make up chokeberries' edible sections find extensive use in the food sector for the production of juices, sauces, jams, fruit teas, and dietary supplements (Table 2) [202, 203].

Aronia fruits, characterized by a high anthocyanin content, are valuable additions to teas, liqueurs, and antioxidant-rich drinks [209, 210]. Their substantial abundance of anthocyanins suggests their potential as a key element in commercial juices requiring high flavonoid levels [211]. Furthermore, the widely acknowledged limited absorption of anthocyanins in the small intestine enhances their appeal in the food and beverage industry. The utilization of black chokeberries, especially in processed forms, reflects their versatile applications, ranging from the production of dietary supplements to enhancing the color and nutritional content of various food products [212].

Pharmaceutical companies use chokeberry extracts to make syrups and dietary supplements. Because *Aronia* berries have a high pectin content, they are a great addition to mixed jams made with other low-pectin fruits. Addition of chokeberry fruits or preparations can improve the antioxidant content, color, or flavor of jams [213]. Moreover, *A. melanocarpa* berries are a notable source of anthocyanins, which can be utilized as a natural, safe food coloring among grapes (*Vitis* sp.) and roselle (*Hibiscus sabdariffa*) [211].

When compared to the most popular berry teas, *Aronia* berry fruit teas were discovered to be a valuable source of flavonoids and anthocyanins. In a study by Denev et al., the contents of 23 *Aronia* samples collected from different climate conditions were investigated. It was also investigated whether there was a correlation between the chemical composition of berries and the chemical content and

Table 1: Summary of the protective effects of black chokeberry fruit in relation to chronic diseases.

Health Benefits	*Aronia* and its bioactive components	Health outcome	References
Antioxidant activity	Anthocyanins	- Reduce inflammation and oxidative stress	[153]
		- Impact on immunomodulatory effects	[154]
		- Enhancement in lipid profiles	[155]
		- Reduce oxidative stress	[156, 157]
		- Reduce inflammatory markers	[158, 159]
		- Impact on lipid profile - Reduce oxidative status - Reduce blood pressure	[98]
	Anthocyanins/phenolic-rich extract	- Reduction of platelet lipid peroxidation - Reduce oxidative/nitrative stress	[160]
	Polyphenols rich extract	- Reduce pro-oxidative molecules - Increase antioxidant defense	[161]
		- Affect inflammatory markers	[162]
		- Reduce plasma total and low-density lipoprotein	[163]
		- Reduce the activity of angiotensin I–converting enzyme - Function as a hypotensive compound	[164]
		- Impact on oxidative status - Reduce blood pressure	[165, 166]
		- Show cytotoxic effects	[108, 109]
	Aronia	- Protective effects against DNA damage - Reduction in plasma LDL and total cholesterol levels	[167]
Anticancer activity	Crude phenolic extract Purified phenolic-rich extract	- Inhibitory function against colon cancer cells	[168]
	Anthocyanins Flavonoids	- Beneficial impact on plasma thiol levels in breast cancer patients	[169]
	Phenolic-rich extract	- Reduce oxidative/nitrative stress in platelets	[170]
	Aronia extract	- Exhibit antiproliferative effects on breast cancer cells	[171]
	Aronia leaf extract	- Inhibit proliferation of cancer cells - Inhibit cell migration	[145]
	Anthocyanins/phenolic acid	- Enhance the antitumor immune response	[172]
	Proanthocyanidins	- Modulate immune response	[143]
	Anthocyanins	- Exhibit cytotoxic and pro-oxidative effects	[126]
		- Function as a therapeutic agent - Inhibit colon cancer by regulating glutamine metabolism	[173]
		- Inhibit cell proliferation - Induce cell cycle arrest in colon cancer cells	[124, 174]
	Anthocyanins Proanthocyanidins Phenolic acid Flavonoids	- Inhibit proliferation of colon cancer cells	[175]
	Phenolic acids Flavonoids	- Show cytotoxic effects	[109, 176]
	Anthocyanins Flavonoids	- Induce apoptosis in pancreatic cancer cell line	[177]
Antimicrobial	Anthocyanins	- Exhibition antibacterial activity	[91, 110]
	Proanthocyanidins	- Antimicrobial activity against pathogens	[178] [111]
	Aronia extract	- Inhibition food pathogenic and spoilage bacteria	[116]
	Anthocyanins Proanthocyanidins	- Prevention of biofilm formation	[113]

Table 1: Continued.

Health Benefits	*Aronia* and its bioactive components	Health outcome	References
Antimutagenic	Anthocyanins	- Inhibit mutagenic activity	[132]
Antidiabetic effects	Phenolic-rich extract	- Improve hepatic insulin resistance - Reduce blood glucose and serum insulin levels	[138]
	Aronia extract	- Decrease serum glucose levels - Modulate blood lipid level	[140]
		- Exhibit hypoglycemic activity	[179]
		- Inhibit amylase and glucosidase	[180]
	Aronia juice	- Decrease hyperglycemia and hypertriglyceridemia - Decrease plasma triglycerides	[136]
		- Block the accumulation of lipids within white adipose tissues in both normal and obese mice	[106, 181]
		- Modulate blood glucose - Reduce hemoglobin A1c levels	[182]
		- Inhibit glucosidase	[183]
	Anthocyanins	- Regulate blood glucose - Improve hyperinsulinemia	[184]
		- Protect pancreatic β-cells - Modulate oxidative stress - Exhibit antioxidant function	[185]
		- Exhibit immunomodulatory function - Protection against insulin deficiency	[186]
	Polyphenolic extract	- Reduce cholesterol level - Exhibit hypoglycemic activity	[187]
		- Reduce adipogenesis - Modulate glucose tolerance - Modulate lipid levels	[188]
Anti-inflammatory effects	*Aronia* extract	- Interleukin-6 secretion prevention - Interleukin-10 excretion promotion	[142]
		- Significant anti-inflammatory effect on rats with endotoxin-induced uveitis - Antiocular inflammatory action relation	[144]
		- Decrease ICAM-1 and VCAM-1 expression levels - Decrease mRNA expression levels of ICAM-1 and VCAM-1	[11]
		- Increase in adiponectin levels	[105]
	Aronia juice	- Anti-inflammatory effects on swollen paws	[143]
	Aronia leaves	- Decrease expression levels of TNF-α and interleukin-6	[145]
Other studies	*Aronia* extract	- Regulate blood pressure - Reduce glycemia - Modulate lipid profile	[106]
	Aronia juice	- Decrease in anxiety and depression-like symptoms in rats	[189]
	Aronia extract	- Antineurodegenerative activity	[179]
	Aronia juice	- Reduce lipidemia	[190]
	Aronia juice	- Decrease LDL fraction - Regulate total cholesterol levels	[191]
	Aronia juice	- Decrease systemic inflammation - Modulate fatty acid and lipid concentration	[192]
	Polyphenols	- Regulate gut microbiota - Modulate lipid metabolism	[12, 193]
	Phenolic-rich extract	- Reduce liver disease symptoms - Modulate gut microbiota	[194]
	Anthocyanins	- Reduce expression of cytokines and adhesion molecules - Modulate inflammation in vascular endothelial cells	[195]
	Phenolic-rich extract	- Free radical scavenger activity	[196]

antioxidant activity of *Aronia* functional drinks. They discovered that the variations in the chemical content of the fruits produced functional foods with markedly different chemical profiles and antioxidant capacities [74]. Using liquid chromatography coupled with electrospray-ionization quadrupole time-of-flight mass spectrometry (LC-ESI-QTOF/MS) and high-performance liquid chromatography with diode-array detection (HPLC-DAD), the bioactive

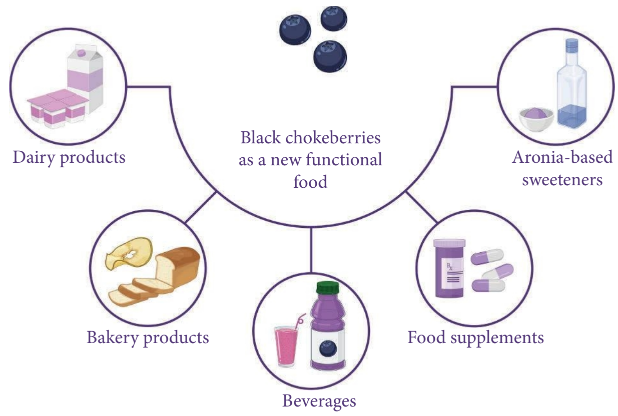

Figure 7: *Aronia*-based functional foods in the food industry [202, 203].

Table 2: Studies of *Aronia* containing functional foods development.

Functional food category	Aronia and its bioactive components	Functional property and potential health benefits/outcomes	References
Chokeberry juice	*Aronia* berries	Increased antioxidant capacity	[18]
Snack pellets	*Aronia* berries	Increased antioxidant capacity and reduced fat absorption index	[205]
Yogurt	Fermented *Aronia* juice	Increased antioxidant capacity	[206]
Tea	*Aronia* berries as powder	Increased antioxidant capacity	[104]
Kefir	Fresh *Aronia* juice	Increased antioxidant capacity	[207]
Milk	*Aronia* berries as powder	Increased antioxidant capacity and higher acceptability	[208]

phenolics in *Aronia* berry teas that were developed as functional beverages were found in a related investigation. Researchers came to the conclusion that new nutritive tea products made with *Aronia* berries might be assessed as novel teas and used as valuable antioxidant sources in the functional food industry [104].

Moreover, fruit extracts, juices, and powders have potential as useful components in the food industry, particularly in the dairy sector [214]. Studies have examined how various plant materials added as functional ingredients affect yogurt's antioxidant qualities and overall qualities. In a study by Nguyen and Hwang, yogurt enriched with 1%, 2%, and 3% *Aronia* juice was examined for its qualitative attributes and antioxidant activity. It was discovered that as the amount of *Aronia* juice increased, so did the overall polyphenol and flavonoid concentrations. Their findings suggested that *Aronia* juice might be a helpful addition to enhance yogurt's flavor and antioxidant capacity [206].

Black chokeberry has gained appeal as an herbal medicine in addition to being used in the culinary business. It is widely used as an all-natural remedy to lower blood pressure and prevent atherosclerosis. For instance, North American native black chokeberry bushes have long been used medicinally to cure fever, coughing, and colds [215].

According to the in vitro and in vivo studies, black chokeberries have a high edible value and excellent development potential for their products. The majority of the nutritional value and health advantages of black chokeberries are derived from their exceptional antioxidant properties, making them one of the most abundant sources of ingestible polyphenols. Additionally, it is anticipated that customers' demand for functional foods will grow as black currant food products become more and more popular. To evaluate the health potential, safety, and modes of action of chokeberries, however, as with other natural plants and therapeutic items, a thorough investigation is necessary.

6. Conclusion Remarks Future Remark

Black chokeberry contains a variety of bioactive substances with numerous health-promoting qualities. Recent research has revealed that the consumption of black chokeberry products offers various health benefits, particularly in relation to cardiovascular disorders, hyperlipidemia, hypercholesterolemia, hypertension, and diabetes. Beyond its impact on erythrocyte function and homeostasis, black chokeberry has therapeutic effects on both of these parameters in individuals with metabolic syndrome. Furthermore, research has demonstrated black chokeberry's anti-inflammatory and antimutagenic actions, as well as its ability to counteract the harmful effects of exogenous substances in the human body. A potential preventive measure against leukemia, intestinal, breast, and other cancers is the ability of black chokeberry to hinder the formation of cancer stem cells.

Thus far, research has revealed numerous benefits of incorporating black chokeberries into the regular diet. Due to the possible health advantages of black chokeberry fruit and its derivatives, all of the fruit's components may find usage in the food sector as a valuable source of antioxidants and nutrients. In summary, chokeberry, a lesser-known berry, is one of the richest plant sources, especially for phenolic components such as procyanidins and anthocyanins. Numerous potential medical and therapeutic effects seem to be related to the high concentration of phenolic components and their pattern. More research is required to comprehend the positive benefits documented thus far from a mechanistic perspective as well. Nonetheless, it would be ideal if *Aronia* food products became more widely known, expanding the range of nutritious berry fruits available to customers in the future.

Data Availability Statement

The authors have nothing to report.

Disclosure

The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Conflicts of Interest

The authors declare no conflicts of interest.

Funding

This research received no external funding.

References

[1] P. J. Leonard, M. H. Brand, B. A. Connolly, and S. G. Obae, "Investigation of the Origin of Aronia Mitschurinii Using Amplified Fragment Length Polymorphism Analysis," *HortScience* 48, no. 5 (2013): 520–524, https://doi.org/10.21273/HORTSCI.48.5.520.

[2] A. Shipunov, S. Gladkova, P. Timoshina, et al., "Mysterious Chokeberries: New Data on the Diversity and Phylogeny of *Aronia medik*. (Rosaceae)," *European Journal of Taxonomy* 2019, no. 570 (2019): 1–14, https://doi.org/10.5852/ejt.2019.570.

[3] S. G. Obae, M. H. Brand, B. A. Connolly, R. R. Beasley, and S. L. Lance, "Microsatellite Markers for *Aronia melanocarpa* (Black Chokeberry) and Their Transferability to Other Aronia Species," *HortScience* 52, no. 1 (2017): 20–23, https://doi.org/10.21273/HORTSCI11276-16.

[4] M. Smolik, I. D. Ochmian, and B. Smolik, "RAPD and ISSR Methods Used for Fingerprinting Selected, Closely Related Cultivars of *Aronia melanocarpa*," *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 39, no. 2 (2011): 276, https://doi.org/10.15835/nbha3926268.

[5] J. D. Mahoney, S. Wang, L. A. Iorio, et al., "De Novo Assembly of a Fruit Transcriptome Set Identifies AmMYB10 as a Key Regulator of Anthocyanin Biosynthesis in *Aronia melanocarpa*," *BMC Plant Biology* 22, no. 1 (2022): 143, https://doi.org/10.1186/s12870-022-03518-8.

[6] I. D. Ochmian, J. Grajkowski, and M. Smolik, "Comparison of Some Morphological Features, Quality and Chemical Content of Four Cultivars of Chokeberry Fruits (*Aronia melanocarpa*)," *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 40, no. 1 (2012): 253, https://doi.org/10.15835/nbha4017181.

[7] J. Richard, "Pankhurst† *Aronia melanocarpa* (Michaux) Elliott," https://floranorthamerica.org/Aronia_melanocarpa.

[8] L. Jakobek, M. Drenjančević, V. Jukić, and M. Šeruga, "Phenolic Acids, Flavonols, Anthocyanins and Antiradical Activity of "Nero", "Viking", "Galicianka" and Wild Chokeberries," *Scientia Horticulturae* 147 (2012): 56–63, https://doi.org/10.1016/j.scienta.2012.09.006.

[9] V. Kitrytė, V. Kraujalienė, V. Šulniūtė, A. Pukalskas, and P. R. Venskutonis, "Chokeberry Pomace Valorization into Food Ingredients by Enzyme-Assisted Extraction: Process Optimization and Product Characterization," *Food and Bioproducts Processing* 105 (2017): 36–50, https://doi.org/10.1016/j.fbp.2017.06.001.

[10] K. Wilkes, L. R. Howard, C. Brownmiller, and R. L. Prior, "Changes in Chokeberry (*Aronia melanocarpa* L.) Polyphenols During Juice Processing and Storage," *Journal of Agricultural and Food Chemistry* 62, no. 18 (2014): 4018–4025, https://doi.org/10.1021/jf404281n.

[11] D. Zapolska-Downar, D. Bryk, M. Małecki, K. Hajdukiewicz, and D. Sitkiewicz, "*Aronia melanocarpa* Fruit Extract Exhibits Anti-Inflammatory Activity in Human Aortic Endothelial Cells," *European Journal of Nutrition* 51, no. 5 (2012): 563–572, https://doi.org/10.1007/s00394-011-0240-1.

[12] Y. Zhu, J. Zhang, Y. Wei, et al., "The Polyphenol-Rich Extract From Chokeberry (*Aronia melanocarpa* L.) Modulates Gut Microbiota and Improves Lipid Metabolism in Diet-Induced Obese Rats," *Nutrition and Metabolism* 17, no. 1 (2020): 54, https://doi.org/10.1186/s12986-020-00473-9.

[13] M. Cebova, J. Klimentova, P. Janega, and O. Pechanova, "Effect of Bioactive Compound of *Aronia melanocarpa* on Cardiovascular System in Experimental Hypertension," *Oxidative Medicine and Cellular Longevity* 2017 (2017): 8156594–8156598, https://doi.org/10.1155/2017/8156594.

[14] G. Engels and J. Brinckmann, "Black Chokeberry *Aronia melanocarpa*," *American Botanical Council* (2014): 1–5.

[15] F. Fruit, P. Announcements, M. Henney, M. Kobuszynska, and A. Specialist, *Poland Pursues Becoming the Berry Supplier for Russia and the EU* (2013).

[16] S. Poyraz Engin and Y. Boz, "Aronia (*Aronia melanocarpa* (Michx) Elliot) Cultivation in Turkey and in the World," *Bahçe* 48 (2019): 247–252.

[17] S. E. Kulling and H. M. Rawel, "Chokeberry (*Aronia melanocarpa*)—A Review on the Characteristic Components and Potential Health Effects," *Planta Medica* 74, no. 13 (2008): 1625–1634, https://doi.org/10.1055/s-0028-1088306.

[18] J. Oszmiański and A. Wojdylo, "*Aronia melanocarpa* Phenolics and Their Antioxidant Activity," *European Food Research and Technology* 221, no. 6 (2005): 809–813, https://doi.org/10.1007/s00217-005-0002-5.

[19] K. Z. Wawer and I. Małgorzata Gralec, "*Aronia melanocarpa* Berries: Phenolics Composition and Antioxidant Properties Changes During Fruit Development and Ripening," *Emirates Journal of Food and Agriculture* 31 (2019): 214, https://doi.org/10.9755/ejfa.2019.v31.i3.1921.

[20] I. Juranović Cindrić, M. Zeiner, D. Mihajlov-Konanov, and G. Stingeder, "Inorganic Macro- and Micronutrients in "Superberries" Black Chokeberries (*Aronia melanocarpa*) and Related Teas," *International Journal of Environmental Research and Public Health* 14, no. 5 (2017): 539, https://doi.org/10.3390/ijerph14050539.

[21] L. Pop, R. Costa, A. A. S. Ănică, and L. Tudoreanu, "Mineral Nutritional Value of Products Containing Aronia Fruits and Juices: A Review," *Horticulture* (2022): 846–856.

[22] F. Demirel, R. Uğur, G. C. Popescu, S. Demirel, and M. Popescu, "Usage of Machine Learning Algorithms for Establishing an Effective Protocol for the in Vitro Micropropagation Ability of Black Chokeberry (*Aronia melanocarpa* (Michx.) Elliott)," *Horticulturae* 9, no. 10 (2023): 1112, https://doi.org/10.3390/horticulturae9101112.
[23] H. M. M. Almokar and L. Pırlak, "Propagation of Aronia (*Aronia melanocarpa*) With Tissue Culture," *Selcuk Journal of Agricultural and Food Sciences* 32, no. 3 (2018): 549–558, https://doi.org/10.15316/sjafs.2018.136.
[24] Y. Long, Y. Yang, G. Pan, and Y. Shen, "New Insights Into Tissue Culture Plant-Regeneration Mechanisms," *Frontiers of Plant Science* 13 (2022): 926752, https://doi.org/10.3389/fpls.2022.926752.
[25] R. M. Moraes, A. L. Cerdeira, and M. V. Lourenço, "Using Micropropagation to Develop Medicinal Plants Into Crops," *Molecules* 26, no. 6 (2021): 1752, https://doi.org/10.3390/molecules26061752.
[26] Y. Ren, T. Frank, G. Meyer, et al., "Potential Benefits of Black Chokeberry (*Aronia melanocarpa*) Fruits and Their Constituents in Improving Human Health," *Molecules* 27, no. 22 (2022): 7823, https://doi.org/10.3390/molecules27227823.
[27] M. H. Brand, "Propagation of Aronia by Seed, Cuttings, Tissue Culture and Grafting©," *Acta Horticulturae* 1174 (2017): 197–204, https://doi.org/10.17660/ActaHortic.2017.1174.41.
[28] V. Isac and C. Plopa, "In Vitro Propagation Technology for the Black Chokeberry *Aronia melanocarpa* (Michx.) Elliot," *Fruit Growing Research* 38 (2022): 202–207, https://doi.org/10.33045/fgr.v38.2022.29.
[29] İ. Eskİmez and M. Polat, "Aronya (*Aronia melanocarpa* (Michx.) Elliott)'Nın Mikroçoğaltımında Bitki Büyüme Düzenleyicilerinin Etkileri," *Meyve Bilim* 10 (2023): 92–99, https://doi.org/10.51532/meyve.1189817.
[30] C. Yağcı, "Bitki Doku Kültürü Yoluyla Üretilen Flavonoitler Flavonoids Producing by Plant Tissue Culture," *Türk Bilimsel Derlemeler Dergisi* 1 (2008): 47–58.
[31] O. Borsai, D. Clapa, A. L. Fira, K. Szabo, A. F. S. Dumitra, and D. Pamfil, *In Vitro Propagation of Aronia melanocarpa (Michx.) Elliott* (2017).
[32] F. Celebi-Toprak and A. R. Alan, "A Successful Micropropagation Protocol for Three Aronia (*Aronia melanocarpa*) Cultivars," *Acta Horticulturae* no. 1285 (2020): 173–176, https://doi.org/10.17660/ActaHortic.2020.1285.27.
[33] S. Prabhu, A. Molath, H. Choksi, S. Kumar, and R. Mehra, "Classifications of Polyphenols and Their Potential Application in Human Health and Diseases," *International Journal of Physiology, Nutrition and Physical Education* 6, no. 1 (2021): 293–301, https://doi.org/10.22271/journalofsport.2021.v6.i1e.2236.
[34] R. K. Singla, A. K. Dubey, A. Garg, et al., "Natural Polyphenols: Chemical Classification, Definition of Classes, Subcategories, and Structures," *Journal of AOAC International* 102, no. 5 (2019): 1397–1400, https://doi.org/10.5740/jaoacint.19-0133.
[35] J. B. Harborne, "Do Natural Plant Phenols Play a Role in Ecology?" *Acta Horticulturae* no. 381 (1994): 36–45, https://doi.org/10.17660/ActaHortic.1994.381.1.
[36] K. B. Pandey and S. I. Rizvi, "Plant Polyphenols as Dietary Antioxidants in Human Health and Disease," *Oxidative Medicine and Cellular Longevity* 2, no. 5 (2009): 270–278, https://doi.org/10.4161/oxim.2.5.9498.
[37] S. Quideau, D. Deffieux, C. Douat-Casassus, and L. Pouységu, "Plant Polyphenols: Chemical Properties, Biological Activities, and Synthesis," *Angewandte Chemie* 50, no. 3 (2011): 586–621, https://doi.org/10.1002/anie.201000044.
[38] P. Pietta, M. Minoggio, and L. Bramati, "Plant Polyphenols: Structure, Occurrence and Bioactivity," *Studies in Natural Products Chemistry* 28 (2003): 257–312, https://doi.org/10.1016/S1572-5995(03)80143-6.
[39] G. G. Duthie, P. T. Gardner, and J. A. M. Kyle, "Plant Polyphenols: Are They the New Magic Bullet?" *Proceedings of the Nutrition Society* 62, no. 3 (2003): 599–603, https://doi.org/10.1079/PNS2003275.
[40] H. Nursten, "Practical Polyphenolics: From Structure to Molecular Recognition and Physiological Action," *Trends in Food Science & Technology* 10 (1999): 339, https://doi.org/10.1016/s0924-2244(00)00013-3.
[41] I. Iqbal, P. Wilairatana, F. Saqib, et al., "Plant Polyphenols and Their Potential Benefits on Cardiovascular Health: A Review," *Molecules* 28, no. 17 (2023): 6403, https://doi.org/10.3390/molecules28176403.
[42] A. Rana, M. Samtiya, T. Dhewa, V. Mishra, and R. E. Aluko, "Health Benefits of Polyphenols: A Concise Review," *Journal of Food Biochemistry* 46, no. 10 (2022): e14264, https://doi.org/10.1111/jfbc.14264.
[43] H. Rasouli, M. H. Farzaei, and R. Khodarahmi, "Polyphenols and Their Benefits: A Review," *International Journal of Food Properties* (2017): 1–42, https://doi.org/10.1080/10942912.2017.1354017.
[44] A. Chandrasekara, "Phenolic Acids," in *Encyclopedia of Food Chemistry* (Elsevier, 2019), 535–545.
[45] A. Khoddami, M. Wilkes, and T. Roberts, "Techniques for Analysis of Plant Phenolic Compounds," *Molecules* 18, no. 2 (2013): 2328–2375, https://doi.org/10.3390/molecules18022328.
[46] S. M. Mandal, D. Chakraborty, and S. Dey, "Phenolic Acids Act as Signaling Molecules in Plant-Microbe Symbioses," *Plant Signaling & Behavior* 5, no. 4 (2010): 359–368, https://doi.org/10.4161/psb.5.4.10871.
[47] D. A. Martens, "Relationship Between Plant Phenolic Acids Released During Soil Mineralization and Aggregate Stabilization," *Soil Science Society of America Journal* 66, no. 6 (2002): 1857–1867, https://doi.org/10.2136/sssaj2002.1857.
[48] P. A. Ndakidemi and F. D. Dakora, "Legume Seed Flavonoids and Nitrogenous Metabolites as Signals and Protectants in Early Seedling Development," *Functional Plant Biology* 30, no. 7 (2003): 729, https://doi.org/10.1071/FP03042.
[49] M. Staszowska-Karkut and M. Materska, "Phenolic Composition, Mineral Content, and Beneficial Bioactivities of Leaf Extracts From Black Currant (*Ribes nigrum* L.), Raspberry (*Rubus idaeus*), and Aronia (*Aronia melanocarpa*)," *Nutrients* 12, no. 2 (2020): 463, https://doi.org/10.3390/nu12020463.
[50] P. N. Denev, C. G. Kratchanov, M. Ciz, A. Lojek, and M. G. Kratchanova, "Bioavailability and Antioxidant Activity of Black Chokeberry (*Aronia melanocarpa*) Polyphenols: In Vitro and In Vivo Evidences and Possible Mechanisms of Action: A Review," *Comprehensive Reviews in Food Science and Food Safety* 11, no. 5 (2012): 471–489, https://doi.org/10.1111/j.1541-4337.2012.00198.x.
[51] M. Rodríguez-Werner, P. Winterhalter, and T. Esatbeyoglu, "Phenolic Composition, Radical Scavenging Activity and an Approach for Authentication of *Aronia melanocarpa* Berries, Juice, and Pomace," *Journal of Food Science* 84, no. 7 (2019): 1791–1798, https://doi.org/10.1111/1750-3841.14660.

[52] A. Skoczyñska, I. Jêdrychowska, R. Porêba, et al., "Influence of Chokeberry Juice on Arterial Blood Pressure and Lipid Parameters in Men With Mild Hypercholesterolemia," *Pharmacological Reports* 59 (2007): 177–182.

[53] O. Rop, J. Mlcek, T. Jurikova, et al., "Phenolic Content, Antioxidant Capacity, Radical Oxygen Species Scavenging and Lipid Peroxidation Inhibiting Activities of Extracts of Five Black Chokeberry (*Aronia melanocarpa* (Michx.) Elliot) Cultivars," *Journal of Medicinal Plants Research* 4 (2010): 2431–2437.

[54] B. W. Bolling, R. Taheri, R. Pei, et al., "Harvest Date Affects Aronia Juice Polyphenols, Sugars, and Antioxidant Activity, but Not Anthocyanin Stability," *Food Chemistry* 187 (2015): 189–196, https://doi.org/10.1016/j.foodchem.2015.04.106.

[55] J. K. Hellström, A. N. Shikov, M. N. Makarova, et al., "Blood Pressure-Lowering Properties of Chokeberry (*Aronia mitchurinii*, Var. Viking)," *Journal of Functional Foods* 2 (2010): 163–169, https://doi.org/10.1016/j.jff.2010.04.004.

[56] M. C. Dias, D. C. G. A. Pinto, and A. M. S. Silva, "Plant Flavonoids: Chemical Characteristics and Biological Activity," *Molecules* 26, no. 17 (2021): 5377–16, https://doi.org/10.3390/molecules26175377.

[57] M. Di Ferdinando, C. Brunetti, A. Fini, and M. Tattini, "Flavonoids as Antioxidants in Plants Under Abiotic Stresses," in *Abiotic Stress Responses in Plants* (New York, NY: Springer, 2012), 159–179, https://doi.org/10.1007/978-1-4614-0634-1_9.

[58] R. Mattioli, A. Francioso, L. Mosca, and P. Silva, "Anthocyanins: A Comprehensive Review of Their Chemical Properties and Health Effects on Cardiovascular and Neurodegenerative Diseases," *Molecules* 25, no. 17 (2020): 3809, https://doi.org/10.3390/molecules25173809.

[59] L. Jakobek, M. Šeruga, M. Medvidović-Kosanović, and I. Novak, "Anthocyanin Content and Antioxidant Activity of Various Red Fruit Juices," *Deutsche Lebensmittel-Rundschau: Zeitschrift für Lebensmittelkunde und Lebensmittelrecht* 103 (2007): 58–64.

[60] Y. Zhang, W. Hu, X. Peng, B. Sun, X. Wang, and H. Tang, "Characterization of Anthocyanin and Proanthocyanidin Biosynthesis in Two Strawberry Genotypes During Fruit Development in Response to Different Light Qualities," *Journal of Photochemistry and Photobiology B: Biology* 186 (2018): 225–231, https://doi.org/10.1016/j.jphotobiol.2018.07.024.

[61] W. Zheng and S. Y. Wang, "Oxygen Radical Absorbing Capacity of Phenolics in Blueberries, Cranberries, Chokeberries, and Lingonberries," *Journal of Agricultural and Food Chemistry* 51, no. 2 (2003): 502–509, https://doi.org/10.1021/jf020728u.

[62] X. Wu, L. Gu, R. L. Prior, and S. McKay, "Characterization of Anthocyanins and Proanthocyanidins in Some Cultivars of Ribes, Aronia, and Sambucus and Their Antioxidant Capacity," *Journal of Agricultural and Food Chemistry* 52, no. 26 (2004): 7846–7856, https://doi.org/10.1021/jf0486850.

[63] R. Taheri, B. A. Connolly, M. H. Brand, and B. W. Bolling, "Underutilized Chokeberry (*Aronia melanocarpa*, *Aronia arbutifolia*, *Aronia prunifolia*) Accessions Are Rich Sources of Anthocyanins, Flavonoids, Hydroxycinnamic Acids, and Proanthocyanidins," *Journal of Agricultural and Food Chemistry* 61, no. 36 (2013): 8581–8588, https://doi.org/10.1021/jf402449q.

[64] R. Slimestad, K. Torskangerpoll, H. S. Nateland, T. Johannessen, and N. H. Giske, "Flavonoids From Black Chokeberries, *Aronia melanocarpa*," *Journal of Food Composition and Analysis* 18, no. 1 (2005): 61–68, https://doi.org/10.1016/j.jfca.2003.12.003.

[65] A. Cassidy and C. Kay, "Phytochemicals: Classification and Occurrence," *Encyclopedia of Human Nutrition* 4–4 (2013): 39–46, https://doi.org/10.1016/B978-0-12-375083-9.00226-9.

[66] R. Tsao, "Chemistry and Biochemistry of Dietary Polyphenols," *Nutrients* 2, no. 12 (2010): 1231–1246, https://doi.org/10.3390/nu2121231.

[67] M. A. Kelm, J. F. Hammerstone, G. Beecher, et al., "Concentrations of Proanthocyanidins in Common Foods and Estimations of Normal Consumption," *The Journal of Nutrition* 134, no. 3 (2004): 613–617, https://doi.org/10.1093/jn/134.3.613.

[68] E. H. Hipsley, "Dietary "Fibre" and Pregnancy Toxaemia," *BMJ* 2, no. 4833 (1953): 420–422, https://doi.org/10.1136/bmj.2.4833.420.

[69] B. O. Schneeman and L. F. Tinker, "Dietary Fiber," *Pediatric Clinics of North America* 42, no. 4 (1995): 825–838, https://doi.org/10.1016/S0031-3955(16)39019-8.

[70] H. Trowell, D. Southgate, T. Wolever, A. Leeds, M. Gassull, and D. Jenkins, "Dietary Fibre Redefined," *Lancet* 307, no. 7966 (1976): 967, https://doi.org/10.1016/S0140-6736(76)92750-1.

[71] E. Escudero and Y. P. Álvarez, "González Sánchez Unidad Alimentos," *Revista Brasileira de Ciencias Farmaceuticas* 41 (2005): 15, https://doi.org/10.1590/S1516-93322005000400015.

[72] A. Reißner, S. Al-Hamimi, A. Quiles, et al., "Composition and Physicochemical Properties of Dried Berry Pomace," *Journal of the Science of Food and Agriculture* 99, no. 3 (2019): 1284–1293, https://doi.org/10.1002/jsfa.9302.

[73] V. Schmid, J. Steck, E. Mayer-Miebach, et al., "Impact of Defined Thermomechanical Treatment on the Structure and Content of Dietary Fiber and the Stability and Bioaccessibility of Polyphenols of Chokeberry (*Aronia melanocarpa*) Pomace," *Food Research International* 134 (2020): 109232, https://doi.org/10.1016/j.foodres.2020.109232.

[74] P. Denev, M. Kratchanova, I. Petrova, et al., "Black Chokeberry (*Aronia melanocarpa* (Michx.) Elliot) Fruits and Functional Drinks Differ Significantly in Their Chemical Composition and Antioxidant Activity," *Journal of Chemistry* 2018 (2018): 1–11, https://doi.org/10.1155/2018/9574587.

[75] M. Mikulic-Petkovsek, V. Schmitzer, A. Slatnar, F. Stampar, and R. Veberic, "Composition of Sugars, Organic Acids, and Total Phenolics in 25 Wild or Cultivated Berry Species," *Journal of Food Science* 77, no. 10 (2012): C1064–C1070, https://doi.org/10.1111/j.1750-3841.2012.02896.x.

[76] E. Mayer-Miebach, M. Adamiuk, and D. Behsnilian, "Stability of Chokeberry Bioactive Polyphenols During Juice Processing and Stabilization of a Polyphenol-Rich Material From the By-Product," *Agriculture* 2, no. 3 (2012): 244–258, https://doi.org/10.3390/agriculture2030244.

[77] W. M. N. Ratnayake and C. Galli, "Fat and Fatty Acid Terminology, Methods of Analysis and Fat Digestion and Metabolism: A Background Review Paper," *Annals of Nutrition & Metabolism* 55, no. 1-3 (2009): 8–43, https://doi.org/10.1159/000228994.

[78] I. Piasecka, A. Górska, E. Ostrowska-Ligęza, and S. Kalisz, "The Study of Thermal Properties of Blackberry, Chokeberry and Raspberry Seeds and Oils," *Applied Sciences* 11 (2021): 7704, https://doi.org/10.3390/app11167704.

[79] M. D. Zlatanov, "Lipid Composition of Bulgarian Chokeberry, Black Currant and Rose Hip Seed Oils," *Journal of the Science of Food and Agriculture* 79, no. 12 (1999): 1620–1624, https://doi.org/10.1002/(SICI)1097-0010(199909)79:12%3A1620::AID-JSFA410%3E3.0.CO;2-G.

[80] A. C. Rustan and C. A. Drevon, "Fatty Acids: Structures and Properties," in *Encyclopedia of Life Sciences* (Wiley, 2005), 1–7, https://doi.org/10.1002/9780470015902.a0029198.

[81] F. Dulf, S. Andrei, A. Bunea, and C. Socaciu, "Fatty Acid and Phytosterol Contents of Some Romanian Wild and Cultivated Berry Pomaces," *Chemical Papers* 66, no. 10 (2012): https://doi.org/10.2478/s11696-012-0156-0.

[82] I. Lancrajan, "*Aronia melanocarpa*, a Potential Therapeutic Agent," *Studia Universitatis "Vasile Goldiş", Seria Ştiinţele Vieţii* 22 (2012): 389–394.

[83] L. Červenka, "Moisture Adsorption Characteristics of Black Currant (*Ribes nigrum* l.), Black Elderberry (*Sambucus nigra* l.) and Chokeberry (*Aronia melanocarpa*, [Minchx.] Ell.) Samples at Different Temperatures," *Journal of Food Process Engineering* 34, no. 5 (2011): 1419–1434, https://doi.org/10.1111/j.1745-4530.2009.00507.x.

[84] X. Z. Liu, Y. Ju, N. Bao, et al., "Effects of Polyphenol-Rich *Aronia melanocarpa* Pomace Feeding on Growth Performance, Biochemical Profile, and Meat Quality in Pigs at Weaned and Finishing Stages," *Livestock Science* 252 (2021): 104674, https://doi.org/10.1016/j.livsci.2021.104674.

[85] M. Pieszka, P. Gogol, M. Pietras, and M. Pieszka, "Valuable Components of Dried Pomaces of Chokeberry, Black Currant, Strawberry, Apple and Carrot as a Source of Natural Antioxidants and Nutraceuticals in the Animal Diet," *Annals of Animal Science* 15, no. 2 (2015): 475–491, https://doi.org/10.2478/aoas-2014-0072.

[86] O. Tasinov, I. Dincheva, I. Badjakov, C. Grupcheva, and B. Galunska, "Comparative Phytochemical Analysis of *Aronia melanocarpa* L. Fruit Juices on Bulgarian Market," *Plants* 11, no. 13 (2022): 1655, https://doi.org/10.3390/plants11131655.

[87] T. A. Bennet-Clark, "The Rôle of the Organic Acids in Plant Metabolism: Part I," *New Phytologist* 32, no. 1 (1933): 37–71, https://doi.org/10.1111/j.1469-8137.1933.tb06998.x.

[88] H. B. Vickery and G. W. Pucher, "Organic Acids of Plants," *Annual Review of Biochemistry* 9, no. 1 (1940): 529–544, https://doi.org/10.1146/annurev.bi.09.070140.002525.

[89] J. F. Ma, "Role of Organic Acids in Detoxification of Aluminum in Higher Plants," *Plant and Cell Physiology* 41, no. 4 (2000): 383–390, https://doi.org/10.1093/pcp/41.4.383.

[90] P. Panchal, A. J. Miller, and J. Giri, "Organic Acids: Versatile Stress-Response Roles in Plants," *Journal of Experimental Botany* 72, no. 11 (2021): 4038–4052, https://doi.org/10.1093/jxb/erab019.

[91] D.-H. Kim, H.-W. Lim, S.-H. Kim, et al., "Antibacterial Activity of Crude *Aronia melanocarpa* (Black Chokeberry) Extracts Against *Bacillus cereus*, *Staphylococcus aureus*, *Cronobacter sakazakii*, and *Salmonella enteritidis* in Various Dairy Foods: Preliminary Study," *Journal of Milk Science and Biotechnology* 36, no. 3 (2018): 155–163, https://doi.org/10.22424/jmsb.2018.36.3.155.

[92] L. Catana, M. Catana, E. Iorga, et al., "Vitamin C and Total Polyphenol Content and Antioxidant Capacity of Freshand Processed Fruits of *Aronia melanocarpa*," *Scientific Papers Series B Horticulture* 61 (2017): 433–440.

[93] L. Karakashova, F. Babanovska-Milenkovska, and M. Stojanova, "Comparison of Qualities Properties of Fresh, Frozen and Solar Dried," *Chokeberry Fruits* (2016): 1–4, https://doi.org/10.13140/RG.2.1.4506.1209.

[94] N. Lupascu and R. Sîrbu, "Studies Concerning the Stability if Antioxidant Compounds in *Aronia melanocarpa* Fruits," *European Journal of Medicine and Natural Sciences* 3 (2020): 78, https://doi.org/10.26417/149mik44b.

[95] A. N. Pavlović, J. M. Brcanović, J. N. Veljković, et al., "Characterization of Commercially Available Products of Aronia According to Their Metal Content," *Fruits* 70, no. 6 (2015): 385–393, https://doi.org/10.1051/fruits/2015038.

[96] B. Kaličanin, D. Velimirović, and I. Nešić, "A Study on Mineral Composition of *Aronia melanocarpa* as a Functional Food With Potential Therapeutic Properties," *Journal of Food and Nutrition Research* 61 (2022): 53–60.

[97] A. Sidor and A. Gramza-Michałowska, "Black Chokeberry *Aronia melanocarpa* L.—A Qualitative Composition, Phenolic Profile and Antioxidant Potential," *Molecules* 24, no. 20 (2019): 3710, https://doi.org/10.3390/molecules24203710.

[98] M. Broncel, M. Kozirog, P. Duchnowicz, M. Koter-Michalak, J. Sikora, and J. Chojnowska-Jezierska, "*Aronia melanocarpa* Extract Reduces Blood Pressure, Serum Endothelin, Lipid, and Oxidative Stress Marker Levels in Patients With Metabolic Syndrome," *Medical Science Monitor* 16, no. 1 (2010): 28–34.

[99] M. Mężyńska, M. Brzóska, J. Rogalska, and B. Piłat-Marcinkiewicz, "Extract From *Aronia melanocarpa* L. Berries Prevents Cadmium-Induced Oxidative Stress in the Liver: A Study in A Rat Model of Low-Level and Moderate Lifetime Human Exposure to This Toxic Metal," *Nutrients* 11, no. 1 (2018): 21, https://doi.org/10.3390/nu11010021.

[100] A. R. Jo and J.-Y. Imm, "Effects of Aronia Extract on Lifespan and Age-Related Oxidative Stress in Drosophila melanogaster," *Food Science and Biotechnology* 26, no. 5 (2017): 1399–1406, https://doi.org/10.1007/s10068-017-0180-5.

[101] M.-T. Tolić, I. Krbavčić, P. Vujević, B. Milinović, I. Jurčević, and N. Vahčić, "Effects of Weather Conditions on Phenolic Content and Antioxidant Capacity in Juice of Chokeberries (*Aronia melanocarpa* L.)," *Polish Journal of Food and Nutrition Sciences* 67, no. 1 (2017): 67–74, https://doi.org/10.1515/pjfns-2016-0009.

[102] S. Gancheva, I. Ivanova, A. Atanassova, et al., "Effects of *Aronia melanocarpa* Fruit Juice on Oxidative Stress, Energy Homeostasis, and Liver Function in Overweight and Healthy-Weight Individuals," *Scripta Scientifica Medica* 53, no. 4 (2021): 39, https://doi.org/10.14748/ssm.v0i0.7833.

[103] A. Navrátilová, M. Kovár, J. Kopčeková, J. Mrázová, A. Trakovická, and M. Požgajová, "Protective Effect of *Aronia melanocarpa* Juice Against Acrylamide-Induced Cellular Toxicity," *Journal of Environmental Science and Health, Part B* 58, no. 2 (2023): 139–149, https://doi.org/10.1080/03601234.2023.2172287.

[104] Ö. Tokuşoğlu, "Aronia Berry Tea as Antioxidant Functional Drink: Bioactive Phenolic by HPLC-DAD and LC-ESIQ-TOFF-Mass Spectrometry," *Journal of Food, Health & Technology Innovations* 2 (2019): 47.

[105] M. Naruszewicz, I. Łaniewska, B. Millo, and M. Dłużniewski, "Combination Therapy of Statin With Flavonoids Rich Extract From Chokeberry Fruits Enhanced Reduction in Cardiovascular Risk Markers in Patients After Myocardial Infraction (MI)," *Atherosclerosis* 194, no. 2 (2007): e179–e184, https://doi.org/10.1016/j.atherosclerosis.2006.12.032.

[106] N. Tasic, V. L. J. Jakovljevic, M. Mitrovic, et al., "Black Chokeberry *Aronia melanocarpa* Extract Reduces Blood Pressure, Glycemia and Lipid Profile in Patients With Metabolic Syndrome: A Prospective Controlled Trial," *Molecular and Cellular Biochemistry* 476, no. 7 (2021): 2663–2673, https://doi.org/10.1007/s11010-021-04106-4.

[107] M. J. Alves, I. C. F. R. Ferreira, H. J. C. Froufe, R. M. V. Abreu, A. Martins, and M. Pintado, "Antimicrobial

Activity of Phenolic Compounds Identified in Wild Mushrooms, SAR Analysis and Docking Studies," *Journal of Applied Microbiology* 115, no. 2 (2013): 346–357, https://doi.org/10.1111/jam.12196.

[108] J. P. Rauha, S. Remes, M. Heinonen, et al., "Antimicrobial Effects of Finnish Plant Extracts Containing Flavonoids and Other Phenolic Compounds," *International Journal of Food Microbiology* 56, no. 1 (2000): 3–12, https://doi.org/10.1016/s0168-1605(00)00218-x.

[109] A. Cvetanović, G. Zengin, Z. Zeković, et al., "Comparative In Vitro Studies of the Biological Potential and Chemical Composition of Stems, Leaves and Berries *Aronia melanocarpa*'s Extracts Obtained by Subcritical Water Extraction," *Food and Chemical Toxicology* 121 (2018): 458–466, https://doi.org/10.1016/j.fct.2018.09.045.

[110] H. Deng, J. Zhu, Y. Tong, et al., "Antibacterial Characteristics and Mechanisms of Action of *Aronia melanocarpa* Anthocyanins Against Escherichia coli," *Lwt* 150 (2021): 112018, https://doi.org/10.1016/j.lwt.2021.112018.

[111] I. Liepiņa, V. Nikolajeva, and I. Jākobsone, "Antimicrobial Activity of Extracts From Fruits of *Aronia melanocarpa* and Sorbus aucuparia," *Environmental and Experimental Biology* 11 (2013): 195–199.

[112] S.-J. Kim, A. R. Cho, and J. Han, "Antioxidant and Antimicrobial Activities of Leafy Green Vegetable Extracts and Their Applications to Meat Product Preservation," *Food Control* 29, no. 1 (2013): 112–120, https://doi.org/10.1016/j.foodcont.2012.05.060.

[113] M. Bräunlich, O. Økstad, R. Slimestad, H. Wangensteen, K. Malterud, and H. Barsett, "Effects of *Aronia melanocarpa* Constituents on Biofilm Formation of Escherichia coli and Bacillus Cereus," *Molecules* 18, no. 12 (2013): 14989–14999, https://doi.org/10.3390/molecules181214989.

[114] L. Tamkutė, R. Vaicekauskaitė, B. M. Gil, J. Rovira Carballido, and P. R. Venskutonis, "Black Chokeberry (*Aronia melanocarpa* L.) Pomace Extracts Inhibit Food Pathogenic and Spoilage Bacteria and Increase the Microbiological Safety of Pork Products," *Journal of Food Processing and Preservation* 45, no. 3 (2021): 1–11, https://doi.org/10.1111/jfpp.15220.

[115] L. Grunovaitė, M. Pukalskienė, A. Pukalskas, and P. R. Venskutonis, "Fractionation of Black Chokeberry Pomace into Functional Ingredients Using High Pressure Extraction Methods and Evaluation of Their Antioxidant Capacity and Chemical Composition," *Journal of Functional Foods* 24 (2016): 85–96, https://doi.org/10.1016/j.jff.2016.03.018.

[116] M. Daoutidou, S. Plessas, A. Alexopoulos, and I. Mantzourani, "Assessment of Antimicrobial Activity of Pomegranate, Cranberry, and Black Chokeberry Extracts Against Foodborne Pathogens," *Foods* 10, no. 3 (2021): 486, https://doi.org/10.3390/foods10030486.

[117] S. Park, J. I. Kim, I. Lee, et al., "*Aronia melanocarpa* and Its Components Demonstrate Antiviral Activity Against Influenza Viruses," *Biochemical and Biophysical Research Communications* 440, no. 1 (2013): 14–19, https://doi.org/10.1016/j.bbrc.2013.08.090.

[118] M. Ochnik, D. Franz, M. Sobczyński, et al., "Inhibition of Human Respiratory Influenza A Virus and Human Betacoronavirus-1 by the Blend of Double-Standardized Extracts of *Aronia melanocarpa* (Michx.) Elliot and Sambucus nigra L," *Pharmaceuticals* 15, no. 5 (2022): 619, https://doi.org/10.3390/ph15050619.

[119] M. Eggers, P. Jungke, V. Wolkinger, R. Bauer, U. Kessler, and B. Frank, "Antiviral Activity of Plant Juices and Green Tea Against SARS-CoV-2 and Influenza Virus," *Phytotherapy Research* 36, no. 5 (2022): 2109–2115, https://doi.org/10.1002/ptr.7431.

[120] B. Frank, C. Conzelmann, T. Weil, et al., "Antiviral Activity of Green Tea and Fruit Juices Against SARS-CoV-2, Influenza, and Other," *Viruses* (December 2021): https://doi.org/10.1002/ptr.7431.

[121] J. Lee, K. S. Kim, and K. Na, "Intranasal Administration of an Aronia Extract and Carrageenan Nanocomposite for the Prevention of Influenza A H1N1 Virus Infection," *Journal of Pharmaceutical Investigation* 52, no. 6 (2022): 765–774, https://doi.org/10.1007/s40005-022-00591-x.

[122] J. M. Matés, J. A. Segura, F. J. Alonso, and J. Márquez, "Oxidative Stress in Apoptosis and Cancer: An Update," *Archiv für Toxikologie* 86, no. 11 (2012): 1649–1665, https://doi.org/10.1007/s00204-012-0906-3.

[123] N. Stanisavljević, J. Samardžić, T. Janković, et al., "Antioxidant and Antiproliferative Activity of Chokeberry Juice Phenolics During in Vitro Simulated Digestion in the Presence of Food Matrix," *Food Chemistry* 175 (2015): 516–522, https://doi.org/10.1016/j.foodchem.2014.12.009.

[124] M. Malik, C. Zhao, N. Schoene, M. M. Guisti, M. P. Moyer, and B. A. Magnuson, "Anthocyanin-Rich Extract From *Aronia meloncarpa* E. Induces a Cell Cycle Block in Colon Cancer But Not Normal Colonic Cells," *Nutrition and Cancer* 46, no. 2 (2003): 186–196, https://doi.org/10.1207/S15327914NC4602_12.

[125] C. Zhao, M. M. Giusti, M. Malik, M. P. Moyer, and B. A. Magnuson, "Effects of Commercial Anthocyanin-Rich Extracts on Colonic Cancer and Nontumorigenic Colonic Cell Growth," *Journal of Agricultural and Food Chemistry* 52, no. 20 (2004): 6122–6128, https://doi.org/10.1021/jf049517a.

[126] D. Rugină, Z. Sconţa, L. Leopold, A. Pintea, A. Bunea, and C. Socaciu, "Antioxidant Activities of Chokeberry Extracts and the Cytotoxic Action of Their Anthocyanin Fraction on Hela Human Cervical Tumor Cells," *Journal of Medicinal Food* 15, no. 8 (2012): 700–706, https://doi.org/10.1089/jmf.2011.0246.

[127] H. Park and J. Hong, "Physiological Activities of *Aronia melanocarpa* Extracts on Extraction Solvents," *Korean Journal of Food Preservation* 21, no. 5 (2014): 718–726, https://doi.org/10.11002/kjfp.2014.21.5.718.

[128] T. Sharif, M. Stambouli, B. Burrus, et al., "The Polyphenolic-Rich *Aronia melanocarpa* Juice Kills Teratocarcinomal Cancer Stem-Like Cells, But Not Their Differentiated Counterparts," *Journal of Functional Foods* 5, no. 3 (2013): 1244–1252, https://doi.org/10.1016/j.jff.2013.04.007.

[129] L. Sueiro, G. G. Yousef, D. Seigler, E. G. De Mejia, M. H. Grace, and M. A. Lila, "Chemopreventive Potential of Flavonoid Extracts From Plantation-Bred and Wild *Aronia melanocarpa* (Black Chokeberry) Fruits," *Journal of Food Science* 71, no. 8 (2006): https://doi.org/10.1111/j.1750-3841.2006.00152.x.

[130] A. Sidor, A. Drożdżyńska, and A. Gramza-Michałowska, "Black Chokeberry (*Aronia melanocarpa*) and Its Products as Potential Health-Promoting Factors—An Overview," *Trends in Food Science and Technology* 89 (2019): 45–60, https://doi.org/10.1016/j.tifs.2019.05.006.

[131] R. Balansky, G. Ganchev, M. Iltcheva, et al., "Inhibition of Lung Tumor Development by Berry Extracts in Mice Exposed to Cigarette Smoke," *International Journal of Cancer*

131, no. 9 (2012): 1991–1997, https://doi.org/10.1002/ijc.27486.

[132] K. Gąsiorowski, K. Szyba, B. Brokos, et al., "Antimutagenic Activity of Anthocyanins Isolated From *Aronia melanocarpa* Fruits," *Cancer Letters* 119, no. 1 (1997): 37–46, https://doi.org/10.1016/S0304-3835(97)00248-6.

[133] A. Degenhardt, H. Knapp, and P. Winterhalter, "Separation and Purification of Anthocyanins by High-Speed Countercurrent Chromatography and Screening for Antioxidant Activity," *Journal of Agricultural and Food Chemistry* 48, no. 2 (2000): 338–343, https://doi.org/10.1021/jf990876t.

[134] V. K. Atanasova-Goranova, P. I. Dimova, and G. T. Pevicharova, "Effect of Food Products on Endogenous Generation of N-Nitrosamines in Rats," *British Journal of Nutrition* 78, no. 2 (1997): 335–345, https://doi.org/10.1079/bjn19970151.

[135] L. Shahin, S. Phaal, B. Vaidya, J. Brown, and N. Joshee, "Aronia (Chokeberry): An Underutilized, Highly Nutraceutical Plant," *Journal of Medicinal Plants Studies* 8 (2019): 46, https://doi.org/10.7275/q651-2w57.

[136] S. Valcheva-Kuzmanova, K. Kuzmanov, S. Tancheva, and A. Belcheva, "Hypoglycemic and Hypolipidemic Effects of *Aronia melanocarpa* Fruit Juice in Streptozotocin-Induced Diabetic Rats," *Methods and Findings in Experimental and Clinical Pharmacology* 29, no. 2 (2007): 101–105, https://doi.org/10.1358/mf.2007.29.2.1075349.

[137] S. B. Simeonov, N. P. Botushanov, E. B. Karahanian, M. B. Pavlova, H. K. Husianitis, and D. M. Troev, "Effects of *Aronia melanocarpa* Juice as Part of the Dietary Regimen in Patients With Diabetes Mellitus," *Folia Medica* 44, no. 3 (2002): 20–23.

[138] J. Mu, G. Xin, B. Zhang, Y. Wang, C. Ning, and X. Meng, "Beneficial Effects of *Aronia melanocarpa* Berry Extract on Hepatic Insulin Resistance in Type 2 Diabetes Mellitus Rats," *Journal of Food Science* 85, no. 4 (2020): 1307–1318, https://doi.org/10.1111/1750-3841.15109.

[139] M. Milutinović, R. Veličković Radovanović, K. Šavikin, et al., "Chokeberry Juice Supplementation in Type 2 Diabetic Patients—Impact on Health Status," *Journal of Applied Biomedicine* 17, no. 4 (2019): 218–224, https://doi.org/10.32725/jab.2019.020.

[140] Y.-D. Jeon, S.-H. Kang, K.-H. Moon, et al., "The Effect of Aronia Berry on Type 1 Diabetes In Vivo and In Vitro," *Journal of Medicinal Food* 21, no. 3 (2018): 244–253, https://doi.org/10.1089/jmf.2017.3939.

[141] P. Urios, A.-M. Grigorova-Borsoss, J. Peyroux, and M. Sternberg, "Inhibition de la Glycation Avancée Par Les Flavonoïdes. Implication Nutritionnelle Dans la Prévention Des Complications Du Diabète," *Journal de la Société de Biologie* 201, no. 2 (2007): 189–198, https://doi.org/10.1051/jbio:2007024.

[142] D. A. Martin, R. Taheri, M. H. Brand, A. Draghi, F. A. Sylvester, and B. W. Bolling, "Anti-Inflammatory Activity of Aronia Berry Extracts in Murine Splenocytes," *Journal of Functional Foods* 8 (2014): 68–75, https://doi.org/10.1016/j.jff.2014.03.004.

[143] D. Gajic, T. Saksida, I. Koprivica, et al., "Chokeberry (*Aronia melanocarpa*) Fruit Extract Modulates Immune Response in Vivo and in Vitro," *Journal of Functional Foods* 66 (2020): 103836, https://doi.org/10.1016/j.jff.2020.103836.

[144] K. Ohgami, I. Ilieva, K. Shiratori, et al., "Anti-Inflammatory Effects of Aronia Extract on Rat Endotoxin-Induced Uveitis," *Investigative Ophthalmology & Visual Science* 46, no. 1 (2005): 275–281, https://doi.org/10.1167/iovs.04-0715.

[145] N. D. Thi and E.S. Hwang, "Anti-Cancer and Anti-Inflammatory Activities of Aronia (*Aronia melanocarpa*) Leaves," *Asian Pacific Journal of Tropical Biomedicine* 8, no. 12 (2018): 586–592, https://doi.org/10.4103/2221-1691.248095.

[146] E. Kowalczyk, A. Kopff, P. Fijałkowski, et al., "Effect of Anthocyanins on Selected Biochemical Parameters in Rats Exposed to Cadmium," *Acta Biochimica Polonica* 50, no. 2 (2003): 543–548, https://doi.org/10.18388/abp.2003_3707.

[147] S. Valcheva-Kuzmanova, P. Borisova, B. Galunska, I. Krasnaliev, and A. Belcheva, "Hepatoprotective Effect of the Natural Fruit Juice From *Aronia melanocarpa* on Carbon Tetrachloride-Induced Acute Liver Damage in Rats," *Experimental & Toxicologic Pathology* 56, no. 3 (2004): 195–201, https://doi.org/10.1016/j.etp.2004.04.012.

[148] H. Piotrowska-Kempisty, M. Nowicki, J. Jodynis-Liebert, et al., "Assessment of Hepatoprotective Effect of Chokeberry Juice in Rats Treated Chronically With Carbon Tetrachloride," *Molecules* 25, no. 6 (2020): 1268, https://doi.org/10.3390/molecules25061268.

[149] Z. Wang, Y. Liu, X. Zhao, S. Liu, Y. Liu, and D. Wang, "*Aronia melanocarpa* Prevents Alcohol-Induced Chronic Liver Injury via Regulation of Nrf2 Signaling in C57BL/6 Mice," *Oxidative Medicine and Cellular Longevity* 2020 (2020): 1–13, https://doi.org/10.1155/2020/4054520.

[150] S.-H. Kang, Y.-D. Jeon, K.-H. Moon, et al., "Aronia Berry Extract Ameliorates the Severity of Dextran Sodium Sulfate-Induced Ulcerative Colitis in Mice," *Journal of Medicinal Food* 20, no. 7 (2017): 667–675, https://doi.org/10.1089/jmf.2016.3822.

[151] A. Gramza-Michałowska, A. Sidor, and B. Kulczyński, "Berries as a Potential Anti-Influenza Factor—A Review," *Journal of Functional Foods* 37 (2017): 116–137, https://doi.org/10.1016/j.jff.2017.07.050.

[152] N. Kardum, A. Konić-Ristić, K. Savikin, et al., "Effects of Polyphenol-Rich Chokeberry Juice on Antioxidant/Pro-Oxidant Status in Healthy Subjects," *Journal of Medicinal Food* 17, no. 8 (2014): 869–874, https://doi.org/10.1089/jmf.2013.0135.

[153] Y. Ma, L. Wei, Q. Xu, et al., "Anthocyanin-Rich Phenolic Extracts of Black Chokeberry (*Aronia melanocarpa*) Attenuate Inflammation Induced by Lipopolysaccharide in Raw 264.7 Cells," *Applied Ecology and Environmental Research* 19, no. 1 (2021): 581–596, https://doi.org/10.15666/aeer/1901_581596.

[154] K. Bushmeleva, A. Vyshtakalyuk, D. Terenzhev, T. Belov, E. Nikitin, and V. Zobov, "Antioxidative and Immunomodulating Properties of *Aronia melanocarpa* Extract Rich in Anthocyanins," *Plants* 11, no. 23 (2022): 3333, https://doi.org/10.3390/plants11233333.

[155] C. B. Christiansen, P. B. Jeppesen, K. Hermansen, and S. Gregersen, "The Impact of an 8-Week Supplementation With Fermented and Non-Fermented Aronia Berry Pulp on Cardiovascular Risk Factors in Individuals With Type 2 Diabetes," *Nutrients* 15, no. 24 (2023): 5094, https://doi.org/10.3390/nu15245094.

[156] L. Pilaczynska-Szczesniak, A. Skarpanska-Steinborn, E. Deskur, P. Basta, and M. Horoszkiewicz-Hassan, "The Influence of Chokeberry Juice Supplementation on the Reduction of Oxidative Stress Resulting From an Incremental Rowing Ergometer Exercise," *International Journal of Sport Nutrition and Exercise Metabolism* 15, no. 1 (2005): 48–58, https://doi.org/10.1123/ijsnem.15.1.48.

[157] E. Oprea, B. N. Manolescu, I. C. Fărcăşanu, P. Mladin, and D. Mihele, "Studies Concerning Antioxidant and Hypoglycaemic Activity of *Aronia melanocarpa* Fruits," *Farmacia* 62 (2014): 254–263.

[158] Y. Cui, Y. Lin, X. Meng, et al., "Cyanidin-3-Galactoside From *Aronia melanocarpa* Ameliorates PM10 Induced Pulmonary Injury by Modulating M1/M2 Macrophage Polarization and NRF2/Sirt1 MAPK Signaling," *Journal of Functional Foods* 78 (2021): 104363, https://doi.org/10.1016/j.jff.2021.104363.

[159] M. Banach, M. Wiloch, K. Zawada, W. Cyplik, and W. Kujawski, "Evaluation of Antioxidant and Anti-Inflammatory Activity of Anthocyanin-Rich Water-Soluble Aronia Dry Extracts," *Molecules* 25, no. 18 (2020): 4055, https://doi.org/10.3390/molecules25184055.

[160] B. Olas, B. Wachowicz, P. Nowak, et al., "Studies on Antioxidant Properties of Polyphenol-Rich Extract From Berries of *Aronia melanocarpa* in Blood Platelets," *Journal of Physiology & Pharmacology* 59, no. 4 (2008): 823–835.

[161] I. Milosavljevic, V. Jakovljevic, D. Petrovic, et al., "Standardized *Aronia melanocarpa* Extract Regulates Redox Status in Patients Receiving Hemodialysis With Anemia," *Molecular and Cellular Biochemistry* 476, no. 11 (2021): 4167–4175, https://doi.org/10.1007/s11010-021-04225-y.

[162] B. Stankiewicz, M. Cieślicka, J. Mieszkowski, et al., "Effect of Supplementation With Black Chokeberry (*Aronia melanocarpa*) Extract on Inflammatory Status and Selected Markers of Iron Metabolism in Young Football Players: A Randomized Double-Blind Trial," *Nutrients* 15, no. 4 (2023): 975–13, https://doi.org/10.3390/nu15040975.

[163] L. Xie, T. Vance, B. Kim, et al., "Aronia Berry Polyphenol Consumption Reduces Plasma Total and Low-Density Lipoprotein Cholesterol in Former Smokers Without Lowering Biomarkers of Inflammation and Oxidative Stress: A Randomized Controlled Trial," *Nutrition Research* 37 (2017): 67–77, https://doi.org/10.1016/j.nutres.2016.12.007.

[164] J. Sikora, M. Broncel, and E. Mikiciuk-Olasik, "*Aronia melanocarpa* Elliot Reduces the Activity of Angiotensin I-Converting Enzyme—In Vitro and EX Vivo Studies," *Oxidative Medicine and Cellular Longevity* 2014 (2014): 1–7, https://doi.org/10.1155/2014/739721.

[165] N. Kardum, B. Milovanović, K. Šavikin, et al., "Beneficial Effects of Polyphenol-Rich Chokeberry Juice Consumption on Blood Pressure Level and Lipid Status in Hypertensive Subjects," *Journal of Medicinal Food* 18, no. 11 (2015): 1231–1238, https://doi.org/10.1089/jmf.2014.0171.

[166] B. Olas, M. Kedzierska, B. Wachowicz, A. Stochmal, and W. Oleszek, "Effects of Polyphenol-Rich Extract From Berries of *Aronia melanocarpa* on the Markers of Oxidative Stress and Blood Platelet Activation," *Platelets* 21, no. 4 (2010): 274–281, https://doi.org/10.3109/09537101003612821.

[167] T. Bakuradze, D. Becker, J. Reischmann, P. Meiser, J. Galan, and E. Richling, "Protection From DNA Damage by Use of an Aronia Food Supplement—Results From a Pilot Human Intervention Study," *Current Pharmacology Reports* 5, no. 3 (2019): 188–195, https://doi.org/10.1007/s40495-019-00178-5.

[168] K. Owczarek, D. Sosnowska, D. Kajszczak, and U. Lewandowska, "Evaluation of Phenolic Composition, Antioxidant and Cytotoxic Activity of *Aronia melanocarpa* Leaf Extracts," *Journal of Physiology & Pharmacology* 73, no. 2 (2022): 233–243, https://doi.org/10.26402/jpp.2022.2.06.

[169] M. Kędzierska, R. Głowacki, U. Czernek, et al., "Changes in Plasma Thiol Levels Induced by Different Phases of Treatment in Breast Cancer; The Role of Commercial Extract From Black Chokeberry," *Molecular and Cellular Biochemistry* 372, no. 1-2 (2013): 47–55, https://doi.org/10.1007/s11010-012-1444-2.

[170] M. Kedzierska, B. Olas, B. Wachowicz, et al., "Effects of the Commercial Extract of Aronia on Oxidative Stress in Blood Platelets Isolated From Breast Cancer Patients After the Surgery and Various Phases of the Chemotherapy," *Fitoterapia* 83, no. 2 (2012): 310–317, https://doi.org/10.1016/j.fitote.2011.11.007.

[171] J. Wenzel, L. Wang, S. Horcasitas, et al., "Influence of Supercritical Fluid Extraction Parameters in Preparation of Black Chokeberry Extracts on Total Phenolic Content and Cellular Viability," *Food Science and Nutrition* 8, no. 7 (2020): 3626–3637, https://doi.org/10.1002/fsn3.1645.

[172] D. Gajić, I. Stojanović, I. Koprivica, et al., "Chokeberry (*Aronia melanocarpa*) Fruit Extract Abrogates Melanoma Progression Through Boosting up IFN-γ-Producing Cells," *Journal of Functional Foods* 95 (2022): 105185, https://doi.org/10.1016/j.jff.2022.105185.

[173] W. Yu, J. Gao, R. Hao, et al., "*Aronia melanocarpa* Elliot Anthocyanins Inhibit Colon Cancer by Regulating Glutamine Metabolism," *Food Bioscience* 40 (2021): 100910, https://doi.org/10.1016/j.fbio.2021.100910.

[174] J. Wei, W. Yu, R. Hao, J. Fan, and J. Gao, "Anthocyanins From *Aronia melanocarpa* Induce Apoptosis in Caco-2 Cells Through Wnt/β-Catenin Signaling Pathway," *Chemistry and Biodiversity* 17, no. 11 (2020): e2000654, https://doi.org/10.1002/cbdv.202000654.

[175] Z. Caliskan, M. F. Yucel, Y. Celikok, V. Guler, and S. Duranay, "A Preliminary Study of the Anti-Proliferative Effect of *Aronia melanocarpa* Extract on Human Colon Cancer Cells and Its Relation With Human TERT Protein," *Experimental Biomedical Research* 6 (2023): 2–98, https://doi.org/10.30714/j-ebr.2023.172.

[176] M. Efenberger-Szmechtyk, A. Nowak, and A. Nowak, "Cytotoxic and DNA-Damaging Effects of *Aronia melanocarpa*, Cornus Mas, and Chaenomeles superba Leaf Extracts on the Human Colon Adenocarcinoma Cell Line Caco-2," *Antioxidants* 9, no. 11 (2020): 1030, https://doi.org/10.3390/antiox9111030.

[177] N. A. A. Thani, S. Keshavarz, B. A. Lwaleed, A. J. Cooper, and H. K. Rooprai, "Cytotoxicity of Gemcitabine Enhanced by Polyphenolics From *Aronia melanocarpa* in Pancreatic Cancer Cell Line AsPC-1," *Journal of Clinical Pathology* 67, no. 11 (2014): 949–954, https://doi.org/10.1136/jclinpath-2013-202075.

[178] P. Denev, M. Číž, M. Kratchanova, and D. Blazheva, "Black Chokeberry (*Aronia melanocarpa*) Polyphenols Reveal Different Antioxidant, Antimicrobial and Neutrophil-Modulating Activities," *Food Chemistry* 284 (2019): 108–117, https://doi.org/10.1016/j.foodchem.2019.01.108.

[179] G. Zdunić, A. A. Aradski, D. Gođevac, et al., "In Vitro Hypoglycemic, Antioxidant and Antineurodegenerative Activity of Chokeberry (*Aronia melanocarpa*) Leaves," *Industrial Crops and Products* 148 (2020): 112328, https://doi.org/10.1016/j.indcrop.2020.112328.

[180] J. Švarc-Gajić, V. Cerdà, S. Clavijo, R. Suárez, G. Zengin, and A. Cvetanović, "Chemical and Bioactivity Screening of Subcritical Water Extracts of Chokeberry (*Aronia melanocarpa*) Stems," *Journal of Pharmaceutical and Biomedical Analysis* 164 (2019): 353–359, https://doi.org/10.1016/j.jpba.2018.11.006.

[181] T. Yamane, M. Imai, S. Handa, et al., "Aronia Juice Supplementation Inhibits Lipid Accumulation in Both Normal

and Obesity Model Mice," *PharmaNutrition* 14 (2020): 100223, https://doi.org/10.1016/j.phanu.2020.100223.

[182] T. Yamane, M. Imai, S. Handa, et al., "Reduction of Blood Glucose and HbA1c Levels by Cyanidin 3,5-Diglucoside in KKAy Mice," *Journal of Functional Foods* 58 (2019): 21–26, https://doi.org/10.1016/j.jff.2019.04.038.

[183] M. Imai, T. Yamane, M. Kozuka, et al., "Caffeoylquinic Acids From Aronia Juice Inhibit Both Dipeptidyl Peptidase IV and α-Glucosidase Activities," *Lebensmittel-Wissenschaft und-Technologie* 129 (2020): 109544, https://doi.org/10.1016/j.lwt.2020.109544.

[184] J. Chen and X. Meng, "*Aronia melanocarpa* Anthocyanin Extracts Improve Hepatic Structure and Function in High-Fat Diet-/Streptozotocin-Induced T2DM Mice," *Journal of Agricultural and Food Chemistry* 70, no. 37 (2022): 11531–11543, https://doi.org/10.1021/acs.jafc.2c03286.

[185] D. Rugină, Z. Diaconeasa, C. Coman, A. Bunea, C. Socaciu, and A. Pintea, "Chokeberry Anthocyanin Extract as Pancreatic β-Cell Protectors in Two Models of Induced Oxidative Stress," *Oxidative Medicine and Cellular Longevity* 2015 (2015): 1–10, https://doi.org/10.1155/2015/429075.

[186] M. Badescu, O. Badulescu, L. Badescu, and M. Ciocoiu, "Effects of *Sambucus nigra* and *Aronia melanocarpa* Extracts on Immune System Disorders Within Diabetes Mellitus," *Pharmaceutical Biology* 53, no. 4 (2015): 533–539, https://doi.org/10.3109/13880209.2014.931441.

[187] A. Jurgoński, J. Juśkiewicz, and Z. Zduńczyk, "Ingestion of Black Chokeberry Fruit Extract Leads to Intestinal and Systemic Changes in a Rat Model of Prediabetes and Hyperlipidemia," *Plant Foods for Human Nutrition* 63, no. 4 (2008): 176–182, https://doi.org/10.1007/s11130-008-0087-7.

[188] N.-H. Kim, J. Jegal, Y. N. Kim, et al., "Chokeberry Extract and Its Active Polyphenols Suppress Adipogenesis in 3T3-L1 Adipocytes and Modulates Fat Accumulation and Insulin Resistance in Diet-Induced Obese Mice," *Nutrients* 10, no. 11 (2018): 1734, https://doi.org/10.3390/nu10111734.

[189] M. Tomić, Đ. Ignjatović, G. Tovilović-Kovačević, et al., "Reduction of Anxiety-Like and Depression-Like Behaviors in Rats After One Month of Drinking *Aronia melanocarpa* Berry Juice," *Food & Function* 7 (2016): 3111–3120, https://doi.org/10.1039/c6fo00321d.

[190] S. Valcheva-Kuzmanova, K. Kuzmanov, V. Mihova, I. Krasnaliev, P. Borisova, and A. Belcheva, "Antihyperlipidemic Effect of *Aronia melanocarpa* Fruit Juice in Rats Fed a High-Cholesterol Diet," *Plant Foods for Human Nutrition* 62, no. 1 (2007): 19–24, https://doi.org/10.1007/s11130-006-0036-2.

[191] E. Daskalova, S. Delchev, Y. Peeva, et al., "Antiatherogenic and Cardioprotective Effects of Black Chokeberry (*Aronia melanocarpa*) Juice in Aging Rats," *Evidence-Based Complementary and Alternative Medicine* 2015 (2015): 1–10, https://doi.org/10.1155/2015/717439.

[192] P. Milic, J. Jeremic, V. Zivkovic, et al., "Effects of Different Dietary Regimes Alone or in Combination With Standardized *Aronia melanocarpa* Extract Supplementation on Lipid and Fatty Acids Profiles in Rats," *Molecular and Cellular Biochemistry* 461, no. 1-2 (2019): 141–150, https://doi.org/10.1007/s11010-019-03597-6.

[193] Y. Zhu, Y. Wei, I. Karras, et al., "Modulation of the Gut Microbiota and Lipidomic Profiles by Black Chokeberry (*Aronia melanocarpa* L.) Polyphenols via the Glycerophospholipid Metabolism Signaling Pathway," *Frontiers in Nutrition* 9 (2022): 913729, https://doi.org/10.3389/fnut.2022.913729.

[194] Y. Kong, T. Yan, Y. Tong, et al., "Gut Microbiota Modulation by Polyphenols From *Aronia melanocarpa* of LPS-Induced Liver Diseases in Rats," *Journal of Agricultural and Food Chemistry* 69, no. 11 (2021): 3312–3325, https://doi.org/10.1021/acs.jafc.0c06815.

[195] T. Iwashima, Y. Kudome, Y. Kishimoto, et al., "Aronia Berry Extract Inhibits TNF-α-Induced Vascular Endothelial Inflammation Through the Regulation of STAT3," *Food & Nutrition Research* 63, no. 0 (2019): 1–8, https://doi.org/10.29219/fnr.v63.3361.

[196] L. Jakobek, M. Seruga, and P. Krivak, "The Influence of Interactions Among Phenolic Compounds on the Antiradical Activity of Chokeberries (*Aronia melanocarpa*)," *International Journal of Food Sciences & Nutrition* 62, no. 4 (2011): 345–352, https://doi.org/10.3109/09637486.2010.534438.

[197] F. Giampieri, T. Y. Forbes-Hernandez, M. Gasparrini, et al., "Strawberry as a Health Promoter: An Evidence Based Review," *Food & Function* 6, no. 5 (2015): 1386–1398, https://doi.org/10.1039/c5fo00147a.

[198] L. A. Kresty, S. R. Mallery, and G. D. Stoner, "Black Raspberries in Cancer Clinical Trials: Past, Present and Future," *Journal of Berry Research* 6, no. 2 (2016): 251–261, https://doi.org/10.3233/JBR-160125.

[199] D. Sun-Waterhouse, "The Development of Fruit-Based Functional Foods Targeting the Health and Wellness Market: A Review," *International Journal of Food Science and Technology* 46, no. 5 (2011): 899–920, https://doi.org/10.1111/j.1365-2621.2010.02499.x.

[200] N. Ćujić, N. Kardum, K. Šavikin, G. Zdunić, T. Janković, and N. Menković, "Potential of Chokeberry (*Aronia melanocarpa* L.) as a Therapeutic Food," in *Therapeutic Foods* (Elsevier, 2018), 209–237, https://doi.org/10.1016/B978-0-12-811517-6.00007-6.

[201] A. S. Aksoy, "A Review of the Nutritional Profile, Chemical Composition and Potential Health Benefits of *Aronia melanocarpa* (Chokeberry) Berries and Products," *Turkish Journal of Agriculture—Food Science and Technology* 11, no. 10 (2023): 2027–2043, https://doi.org/10.24925/turjaf.v11i10.2027-2043.6305.

[202] C. Chrubasik, G. Li, and S. Chrubasik, "The Clinical Effectiveness of Chokeberry: A Systematic Review," *Phytotherapy Research* 24, no. 8 (2010): 1107–1114, https://doi.org/10.1002/ptr.3226.

[203] M. Vagiri and M. Jensen, "Influence of Juice Processing Factors on Quality of Black Chokeberry Pomace as a Future Resource for Colour Extraction," *Food Chemistry* 217 (2017): 409–417, https://doi.org/10.1016/j.foodchem.2016.08.121.

[204] T. Jurikova, J. Mlcek, S. Skrovankova, et al., "Fruits of Black Chokeberry *Aronia melanocarpa* in the Prevention of Chronic Diseases," *Molecules* 22, no. 6 (2017): 944, https://doi.org/10.3390/molecules22060944.

[205] A. Wójtowicz, M. Combrzyński, B. Biernacka, et al., "Fresh Chokeberry (*Aronia melanocarpa*) Fruits as Valuable Additive in Extruded Snack Pellets: Selected Nutritional and Physiochemical Properties," *Plants* 12, no. 18 (2023): 3276, https://doi.org/10.3390/plants12183276.

[206] L. Nguyen and E.-S. Hwang, "Quality Characteristics and Antioxidant Activity of Yogurt Supplemented With Aronia (*Aronia melanocarpa*) Juice," *Preventive Nutrition and Food Science* 21, no. 4 (2016): 330–337, https://doi.org/10.3746/pnf.2016.21.4.330.

[207] P. Joyet, A. Mokhtari, E. Riboulet-Bisson, et al., "Enzymes Required for Maltodextrin Catabolism in *Enterococcus faecalis* Exhibit Novel Activities," *Applied and Environmental*

Microbiology 83, no. 13 (2017): e00038-17, https://doi.org/10.1128/AEM.00038-17.

[208] S.-H. Kim, J.-W. Chon, K.-Y. Song, D. Jeong, and K.-H. Seo, "Sensory Attributes of Market Milk, Yogurt, and Kefir Supplemented With Various Concentrations of *Aronia melanocarpa* (Black Chokeberry) Powder: A Preliminary Study," *Journal of Milk Science and Biotechnology* 37, no. 2 (2019): 108–114, https://doi.org/10.22424/jmsb.2019.37.2.108.

[209] M. J Bermúdez-Soto and F. A Tomás-Barberán, "Evaluation of Commercial Red Fruit Juice Concentrates as Ingredients for Antioxidant Functional Juices," *European Food Research and Technology* 219, no. 2 (2004): 133–141, https://doi.org/10.1007/s00217-004-0940-3.

[210] E. González-Molina, D. A. Moreno, and C. García-Viguera, "Aronia-Enriched Lemon Juice: A New Highly Antioxidant Beverage," *Journal of Agricultural and Food Chemistry* 56, no. 23 (2008): 11327–11333, https://doi.org/10.1021/jf802790h.

[211] A. Kokotkiewicz, Z. Jaremicz, and M. Luczkiewicz, "Aronia Plants: A Review of Traditional Use, Biological Activities, and Perspectives for Modern Medicine," *Journal of Medicinal Food* 13, no. 2 (2010): 255–269, https://doi.org/10.1089/jmf.2009.0062.

[212] S. Passamonti, U. Vrhovsek, A. Vanzo, and F. Mattivi, "The Stomach as a Site for Anthocyanins Absorption From Food," *FEBS Letters* 544, no. 1-3 (2003): 210–213, https://doi.org/10.1016/s0014-5793(03)00504-0.

[213] W. Kmiecik, Z. Lisiewska, and G. Jaworska, "Effect of Aronia Berry Honey Syrup Used for Sweetening Jams on Their Quality," *Nahrung-Food* 45, no. 4 (2001): 273–279, https://doi.org/10.1002/1521-3803(20010801)45:4%3A273::AID-FOOD273%3E3.0.CO;2-F.

[214] T. C. Wallace and M. M. Giusti, "Determination of Color, Pigment, and Phenolic Stability in Yogurt Systems Colored With Nonacylated Anthocyanins From *Berberis boliviana* L. as Compared to Other Natural/Synthetic Colorants," *Journal of Food Science* 73, no. 4 (2008): C241–C248, https://doi.org/10.1111/j.1750-3841.2008.00706.x.

[215] C. A. Domarew, R. R. Holt, and G. A. Goodman-Snitkoff, "A Study of Russian Phytomedicine and Commonly Used Herbal Remedies," *Journal of Herbal Pharmacotherapy* 2, no. 4 (2002): 31–48, https://doi.org/10.1080/J157v02n04_04.