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Review

Black Chokeberry Extracts (*Aronia melanocarpa*) as an Ingredient of Functional Food – Potential, Challenges and Directions of Development

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Abstract

Functional foods are gaining global importance as consumer demand for products delivering health benefits beyond basic nutrition increases. Black chokeberry (*Aronia melanocarpa*) is a promising candidate in this field, due to its exceptionally high content of bioactive compounds, particularly polyphenols with well-documented health-promoting properties. This article reviews the current state of knowledge on the definition of functional foods and the health benefits of chokeberries, with special emphasis given to their extracts as promising ingredients for novel product development. Efficient recovery methods for bioactive compounds from fruits, pomace, and leaves are discussed, including advances in green extraction technologies such as ultrasound- and microwave-assisted extraction, supercritical fluids, and enzyme-assisted methods. Stabilization approaches, including microencapsulation and freeze-drying, which enhance the stability and bioavailability of phenolics, are also highlighted. The impact of aronia extracts on technological and sensory parameters of food is analyzed. Applications in beverages, baked goods, dairy, and meat products demonstrate improved antioxidant capacity and storability; however, astringency remains a major sensory challenge. Future perspectives include optimizing processing strategies and developing synergistic formulations to maximize health benefits while ensuring consumer acceptance.

Keywords: extracts; chokeberry; functional food; polyphenols; anthocyanins

1. Introduction

From the consumer's perspective, functional foods are products that, in addition to their basic nutritional value, can provide an additional, beneficial effect on the human body – supporting its functioning or reducing the risk of developing non-communicable diseases. Growing consumer nutritional awareness, as well as technological advances in the food industry, are contributing to the dynamic development of this product segment. One way to obtain products with exceptional health-promoting properties is to enrich traditional raw materials with bioactive phytochemical compounds, e.g. by adding plant extracts [1–4]. In this context, black chokeberry (*Aronia melanocarpa*) deserves special attention, as its exceptionally high content of polyphenols, including anthocyanins, flavonoids and phenolic acids, gives it strong antioxidant and anti-inflammatory properties and has a beneficial effect on the health of the cardiovascular system [5–7]. Aronia extracts are available in the form of juice concentrates, powders, water-alcoholic extracts, pomace and others, constituting a valuable functional ingredient that can be used in a wide range of food products. However, introducing products significantly enriched with aronia extracts into the consumer market is associated with technological, sensory and regulatory challenges that must be considered in the process of designing functional foods [8–11].

The aim of this article is to discuss the potential of black chokeberry extracts as a component of functional food, to point out key barriers to their implementation, as well as to identify possible directions for further development in this area.

2. Functional Food – Definitions and Market Significance

The first definition of functional food comes from Japan. Research on this group of products began in 1984. In 1991 the Minister of Health of in Japan approved a new food category called FOSHU (Food for Specified Health Use). As a result of the Japanese government designating this kind product as a separate assortment, legislative work on the legal definition of functional food has begun both in Europe and in the USA. Despite more than three decades of discussion, no agreement has been reached on how to define and regulate the term. Different scientific and governmental institutions use different definitions of functional foods, which differ from each other in terms of the adopted criteria and are not mutually identical. The most frequently quoted definition of functional food in Europe is the one developed under the Functional Food Science in Europe (FUFOSE) program, coordinated by the International Life Sciences Institute (ILSI): "A product can be considered functional only if, at the same time as the basic nutritional value, it exerts an additional effect on one or more functions of the human body, both by improving general and physical conditions and/or reducing the risk of disease development. The amount of intake and form of functional food should be what is normally expected for nutritional purposes. Therefore, it cannot be in the form of pills or capsules, but in the form of normal food" [12–15]. In the United States, a new concept of defining the concept of "functional food" emerged in 1999. Researchers from the Functional Food Center and representatives of the Food and Drug Administration (FDA) and the Academic Society of Functional Foods and Bioactive Compounds (ASFFBC), in cooperation with the United States government, defined "functional food" as: "natural or processed foods that contain biologically active compounds that, in specific, effective, non-toxic amounts, provide clinically proven and documented health benefits using specific biomarkers, to promote optimal health and reduce the risk of chronic/viral diseases and manage their symptoms" [16,17].

According to the latest Global Market Insights report [18], the functional foods segment will experience exceptionally dynamic growth. The compound annual growth rate (CAGR) for 2025–2034 is projected at 8–12%. This trend is driven by the growing interest in healthy lifestyles by consumers, who are increasingly making food and purchasing choices based on information about product composition and their impact on health [19–22]. The fact that the population is aging and the related problem of escalating chronic diseases, generating huge costs of medical care, are also important. This prompts both governments and international organizations to support all activities and regulations that may have a real impact on extending healthy life expectancy [23]. This creates great development opportunities for the food sector, and in particular for the functional food market.

3. Black Chokeberry – Health-Promoting Properties and Bioactive Composition

In the process of designing new food products from the functional food category, it is important to select raw materials with documented health-promoting properties, going beyond the standard nutritional value typical for raw materials of a given category. An example of such a fruit is the black chokeberry (*Aronia melanocarpa*), belonging to the Rosaceae family. Aronia is a fruit with a high content of bioactive compounds, primarily polyphenols, anthocyanins, flavonoids and phenolic acids [24–26], which are responsible for its broad spectrum of health-promoting properties. The scientific literature in this field is very rich [27–30].

Systematic reviews of the literature indicate, among other things, the beneficial effect of aronia supplementation on the reduction of inflammation and oxidative stress in humans and animals. In clinical trials, a decrease in the levels of pro-inflammatory cytokines such as IL-6, TNF- α and CRP was observed, as well as an increase in the anti-inflammatory interleukin IL-10. In addition, aronia supplementation improved the activity of antioxidant enzymes, among other superoxide dismutase

(SOD), catalase (CAT) and glutathione peroxidase (GSH-Px), which confirms its role in the modulation of the immune system and antioxidant protection of the body [31–34].

In studies on animal models, aronia extracts have shown encouraging results in lowering uric acid levels, inhibiting xanthine oxidase activity, and reducing oxidative stress markers such as malondialdehyde, while increasing glutathione levels – indicating strong antioxidant activity and kidney protection in mice with hyperuricemia. These effects were comparable to those of the drug allopurinol, highlighting the potential of aronia as a natural functional agent in the treatment of hyperuricemia and related metabolic disorders [35–38].

Research also indicates the neuroprotective properties of aronia. Aronia extracts have demonstrated an ability to inhibit inflammatory processes in microglial cells and protect neurons against amyloid beta-induced apoptosis, which suggests potential in the prevention and treatment of neurodegenerative diseases such as Alzheimer's disease [39]. These mechanisms include modulation of the expression of genes associated with apoptosis, reduction of oxidative stress, and improvement of mitochondrial function [40–43].

With a high content of anthocyanins and polyphenols, the cardioprotective effects of aronia should be obvious [44–46]. Surprisingly, however the results of clinical trials in this regard are ambiguous. Meta-analysis of randomized controlled trials showed that aronia supplementation does not provide significant benefits in terms of cardiometabolic parameters in the general population. However, in selected subgroups, such as those with lower total cholesterol levels or at doses of anthocyanins above 50 mg/day, a beneficial effect was found to lower LDL cholesterol and systolic blood pressure [47]. However, further well-designed studies are needed to confirm these observations [48].

As the latest clinical research results cited above indicate, black chokeberry is a promising ingredient in functional foods. Nevertheless, a product formulated with it or its extracts to truly demonstrate health-promoting effects, the processing methods used, including methods for extracting, concentrating, and stabilizing bioactive ingredients, require extensive optimization, facilitated by technological advancements.

4. Modern Techniques for Obtaining Plant Extracts and Their Formulation

Modern techniques for extracting bioactive substances from plant tissue focus on maximising process efficiency while maintaining the chemical integrity of the extracted compounds, reducing energy consumption, reducing the use of synthetic solvents and being sustainable. This chapter discusses the most important innovative methods of obtaining plant extracts useful or prospective for berry fruits, with particular emphasis on their application in the design of functional foods.

4.1. Ultrasonically-Assisted Extraction (UAE)

Ultrasound-Assisted Extraction (UAE) is a method that uses ultrasonic waves at 20-100 kHz to induce the phenomenon of cavitation in an extraction liquid. Cavitation leads to the formation of gas bubbles, which, when imploding in the vicinity of plant particles, causes mechanical damage to cell walls and thus facilitates the diffusion of bioactive compounds into the solvent. This technology is characterized by high efficiency, low solvent consumption and short process time. UAE is particularly useful for the extraction of phenolic compounds, flavonoids and anthocyanins from fragile raw materials such as fruits, leaves or flowers [49–51].

4.2. Microwave-Assisted Extraction (MAE)

Microwave-Assisted Extraction (MAE) involves dielectric heating of the plant raw material using microwave radiation. Microwave energy causes a rapid increase in temperature and pressure inside plant cells, which leads to their disruption and release of active ingredients into the liquid phase. MAE enables fast and efficient extraction using environmentally friendly solvents such as water or ethanol and is beneficial for the isolation of thermolabile compounds [52].

4.3. Supercritical Fluid Extraction (SFE)

Supercritical Fluid Extraction (SFE) is based on the use of supercritical carbon dioxide (CO₂) (above 31°C and 73 atm) as a solvent. In this state, CO₂ exhibits both liquid and gas properties, which enables the effective dissolution of non-polar components. Due to the low process temperature and the absence of residual solvents, this method is ideal for the production of high-quality food extracts [53].

4.4. Accelerated Solvent Extraction (PLE/ASE)

Pressurized Liquid Extraction (or Accelerated Solvent Extraction) is a technology that involves the use of an extraction liquid at elevated temperatures and pressures. Such conditions improve the solubility and diffusion rate of bioactive compounds. Thanks to its closed system, this technology allows for the quick and efficient extraction of polar compounds, such as phenols or glycosides, from a wide range of plant raw materials. The advantage of this method is the possibility of using friendly solvents (e.g. ethanol, water) and the reduction of process time compared to classic techniques [54].

4.5. Extraction with Natural Eutectic Liquids (NADES)

Natural Deep Eutectic Solvents (NADES) are biodegradable mixtures of natural organic compounds, such as amino acids, sugars or organic acids, which in the right proportions can form liquid systems with good solvent properties. NADES are non-toxic and clean label. They are increasingly used to extract herbs, fruits, and flowers in the production of dietary supplements and functional foods [53].

4.6. Enzyme-Assisted Extraction (EAE)

Enzyme-Assisted Extraction (EAE) uses hydrolytic enzymes such as pectinase, cellulase and hemicellulase to degrade the cellular structure of plant material. These enzymes facilitate the release of active ingredients, especially from fiber-rich tissues or cell walls that are difficult to break mechanically, such as leaves or seed husks. EAE is a benign method, carried out at low temperatures, which reduces the degradation of thermolabile compounds [55].

4.7. Pulsed Electric Field (PEF)

Pulsed Electric Field (PEF) is a non-thermal technology that uses short-term high-voltage pulses to induce electroporation of cell membranes. PEF allows cell permeability to be increased and thus facilitates the release of secondary metabolites into the solvent. This technique is increasingly used as a pre-step before actual extraction (e.g., UAE, IAE, SFE) [52].

4.8. Hybrid Extractions and an Integrated Approach

A new trend in the field of plant extract extraction is the use of integrated techniques, combining the advantages of several methods to optimize the process. Examples include combining UAE with NADES, MAE with enzymes, or PEF with supercritical extraction. A hybrid approach not only improves efficiency, but also makes better use of secondary raw materials and post-industrial waste [56,57].

4.9. Stabilization of Extracts Using Microencapsulation

Microencapsulation plays a key role in protecting and stabilizing the extracted plant extracts, allowing the concentration of the bioactive substance to be increased, also changing the extract form from liquid to powder. This process involves encapsulating bioactive compounds in a casing or protective matrix that protects them from environmental factors such as oxygen, light, high temperature or changes in the pH of the environment. Microencapsulation also enables a controlled release of ingredients and an improvement in their bioavailability and sensory characteristics [58].

The most commonly used microencapsulation methods include:

Spray drying – a technique in which a suspension of an extract is sprayed with a carrier (e.g. maltodextrin) in a drying chamber where hot air evaporates water. The resulting powder contains microcapsules with good solubility and stability. It is a fast, cost-effective and easy method to scale up industrially [59,60].

Co-crystallization – a technique in which a bioactive ingredient is deposited together with an excipient (e.g. sugar, polyols) during crystallization. Molecular structures are formed that stabilize active compounds, protecting them from oxidation and increasing their shelf life under storage conditions [61].

Ion gelation – a method that uses a reaction between a polymer (e.g. sodium alginate) and divalent ions (usually calcium). After mixing the extract with the polymer solution, an ion solution is added to the mixture, which leads to the formation of gel microspheres. This technique is particularly useful for encapsulation of aqueous extracts and ensures their high chemical stability [62,63].

Microencapsulation not only increases the shelf life of active ingredients, but also allows for their better incorporation into various food matrices, such as beverages, yoghurts, snacks or dietary supplements [64,65].

The modern extraction techniques discussed above make it possible to extract bioactive components from diverse tissues, naturally rich in these compounds, which is the basis for the development of functional food. Their use allows for the effective and sustainable extraction of valuable biologically active ingredients from plant raw materials, including processing by-products [66–68]. The choice of the optimal technology should depend on the type of raw material, the chemical properties of the compounds obtained and the target application of the extract. The future of this field lies in the integration of technology, green chemistry and the personalization of functional ingredients according to consumer needs [69–73].

5. Aronia Extracts – Methods of Obtaining

Black chokeberry fruits, which are a rich source of biologically active compounds, including polyphenolic compounds, are an excellent raw material for the production of extracts with high bioactivity. As indicated by the literature data, the leaves of aronia bushes are also considered valuable source of polyphenolic components [74–77]. Depending on the method of preparation of the plant material, the aronia extracts can have different forms and chemical profiles. Figure 1 illustrates most of the possible technological diagrams for the production of aronia-based extracts (fruits, pomace and leaves) used as components of functional foods.

It is worth noting that aronia extracts are used not only in the food industry, but also in cosmetics and dietary supplements. By reviewing the literature on the subject, the articles were selected in which the topic of the use of black chokeberry fruit extracts (*Aronia melanocarpa*) in food products appears. Table 1 presents data for the groups of extracts described in the literature, their production techniques as well as the described effects of applications in the case studies.

Table 1. Characteristics of aronia (*Aronia melanocarpa* L.) extracts used for functional food enhancement: extract type, techniques used, application and technological effects. The data were compiled on the basis of an analysis of scientific publications from 2016–2024.

Extract Type	Technique	Application	The added value of the enriched product	References
Aronia juice concentrate/juice	Cold pressing, filtration, pasteurization, concentration (up to 65 Brix)	Osmotic impregnation before drying fruits,	Improved colour ($\Delta E > 6.0$), increased antioxidant capacity (DPPH +45%); inhibition of anthocyanin degradation by 30% during storage	[78–80]
Aronia powder (freeze-dried)	Freeze-drying (-40°C, 0.1 mbar for 48h); convection drying (60 °C for 24h)	Sweet confectionery, drinks, dairy desserts	Higher polyphenol content (820-900 mg GAE/100g for freeze-dried vs. 470 mg GAE/100g for hot air drying); Anthocyanin behavior above 85%	[56,81,82]
Aronia pomace	Drying with hot air (50-60°C); grinding	Bread, snacks, pectin substitutes dairy products	Improvement of fiber content (up to 22% d.m.), reduction of polyphenol losses by up to 10% during baking, increase in moisture retention in baked goods by 15-18%	[83–86]
Phenolic/polyphenolic extracts	Extraction with 50% ethanol (1:10 m/v, 60°C, 30 min.); ultrasound-assisted (20kHz, 30 min.)	Oil emulsions, meat, supplements	Total polyphenols (TPC) up to 2400 mg GAE/100g; reduction of TBARS in meat by 40-60% during storage (14 days, 4°C)	[49,53,87,88]
Anthocyanin/procyanide extracts	SPE (Solid Phase Extraction) from ethanol and water (50:50), purification on C18 columns. Extraction-adsorption method.	Jelly beans, natural colourants.	Maintaining color stability (up to 85%) at pH 3-4; inhibition of ascorbic acid oxidation by 52%; colour fastness 28 days at 4°C. Increased yield and purity of anthocyanin extract produced from chokeberry pomace using a new method compared to the traditional SPE method.	[89,90]
Aronia leaf extract	Hydroalcoholic extraction (60% ethanol, 1:15 m/v, 40°C, 2h), microencapsulation	Meat products	Reduction of lipid oxidation (TBARS) by 42% in beef burgers, increase in sensory acceptability (panel 8/9 pts.)	[55]
Microencapsulated extracts	Spray drying (inlet temperature 170°C, output temperature 80°C); co-crystallation with maltodextrin or alginate gelation	Yoghurts, dairy desserts, dietary supplements	Retention of 90-95% of polyphenols after 6 weeks of storage, reduction of Maillard reaction, greater stability at pH 4-5.	[64]
Dietary fiber (powder)	Pomace drying (55°C, 24h), mechanical separation	Fermented products (e.g. sheep's milk)	Increase in the number of LAB bacteria by 1.5 log CFU/mL; improved texture, increase in overall sensory acceptance	[91]
Macrogels with aronia juice	Gelation of biopolymers (e.g. carboxymethylcellulose, pea protein)	Functional gummies, gelled products	Anthocyanin retention at 80%, improving antioxidant stability, masking astringent taste	[57]

Natural aronia dye replacing E-131, E-162	Water-ethanol extraction, filtration	Jelly beans, pastries, drinks	Colour fastness for 4 weeks (4°C, pH 3.0); 65% increase in ORAC of gummies, compliance with "clean label" standards	[83,89]
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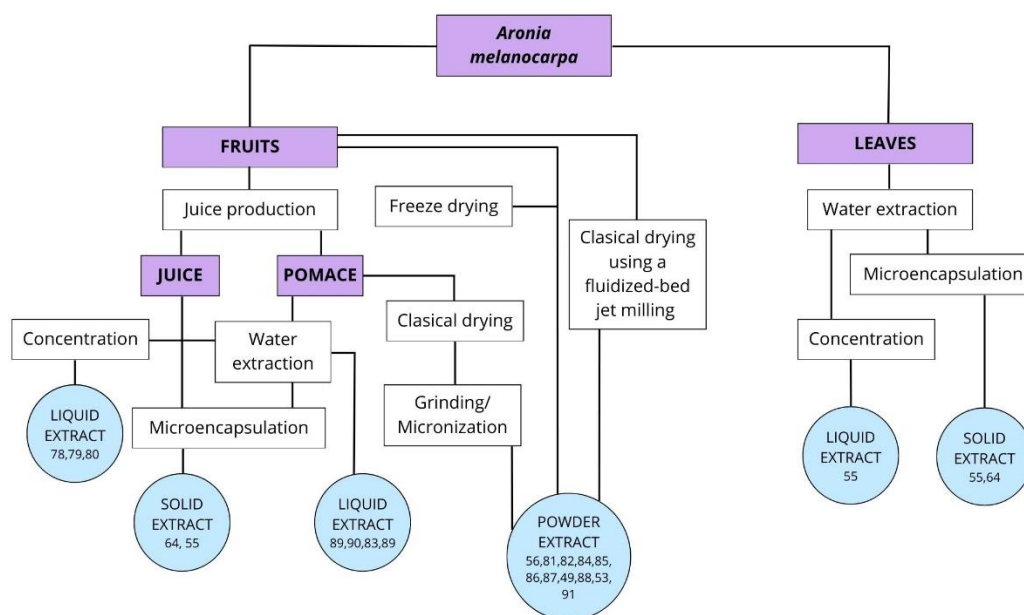


Figure 1. Methods of obtaining black chokeberry extract.

6. Application Possibilities and Stability of Extracts in Technological Processes

The addition of black chokeberry extracts, whether in the form of juice, powder, phenolic extract or microcapsules, increases the content of phenolic compounds and the antioxidant potential of food products. The effectiveness of the enrichment operation depends on the type of matrix, the processing technique and the presence of stability aids (e.g. maltodextrin, vegetable proteins, osmotic carriers). Obtaining a product rich in polyphenol compounds, especially anthocyanins, does not guarantee that their stability will be maintained during storage or trade.

The research by Zlabur et al. [56], investigated the effect of the addition of chokeberry pomace powder on the chemical properties and antioxidant capacity of apple juice, which was subsequently treated with conventional ultrasound and high-intensity ultrasound, in order to extract the components from the juice carrier matrix. Powdered chokeberry pomace increased DPPH activity by more than 45% and the total polyphenol content to 950 mg GAE/100ml, regardless of the applied ultrasound power.

Babaoglu et al. [87], on the other hand, conducted trials to use the antioxidant activity of extract from pomace aronia to improve beef oxidative stability, while testing its antimicrobial activity. These studies showed that the presence of aronia extract in beef reduced the level of substances reacting with thiobarbituric acid (TBARS) by 50-60% during cold storage, which proves the strong antioxidant effect of the extract. In addition, these studies demonstrated the effect of aronia pomace extract on the inhibition of the growth of mesophilic aerobic bacteria, the total number of psychotrophic aerobic bacteria and *E. coli* bacteria. A positive effect on inhibiting the growth of *E. coli* and *S. aureus* bacteria was observed in studies by Li et al. [92]. It was demonstrated that black chokeberry extract has a bacteriostatic effect and extends the shelf life of fresh apples. Kowalczyk et al. [93] also found a beneficial effect of aronia leaf extract on the reduction of lipid oxidation, showing an increase in α -tocopherol retention in beef under refrigerated storage conditions.

The stability of phenolic compounds is highly dependent on both the extraction technology used and the method of their preservation. In the study by Do Thi and Hwang [25], it was found that freeze-drying of extracts allowed the retention of 90-95% of the original content of polyphenols, while convection drying led to a reduction in the content of these compounds to a level of up to 48%. In

studies by Cichowska et al. [94], it was observed that during 12 months of storage of dried apples previously dehydrated in a chokeberry concentrate solution, the level of polyphenol degradation ranged from 40% to 75% compared to the level before storage. The apples were stored at three different temperatures. The best results were observed for the sample subjected to osmotic dehydration and freeze-dried, which was stored at a temperature of 25°C [64,95,96].

Black chokeberry extracts are an exceptionally rich source of anthocyanins, procyanidins and other polyphenolic compounds, thus they have strong antioxidant properties, which makes them effective fixing ingredients. The addition of aronia extract, in addition to increasing the functional value of the product, also affects the protection of the matrix against oxidative degradation, which is very important in long-term storage.

Interesting and really promising results were obtained in the study by Gheorghita et al. [57], where the use of macrogels with aronia juice led to the maintenance of intense color and high antioxidant activity, ORAC (>5000 $\mu\text{mol TE}/100\text{g}$) for 30 days. In this case, aronia extract played a double role – as a natural dye and a strong antioxidant. The phenolic compounds contained in it effectively neutralized free radicals, limiting the oxidation and degradation processes of bioactive food ingredients.

Microencapsulation (e.g. by spray drying or ion gelation) allows phenolic compounds to be protected against environmental factors such as oxygen, light, temperature, which significantly affect the degree of preservation of these compounds. In the study by Tzatsi and Goula [64], a 90 % retention of antioxidant activity was observed after six weeks of storage in powders obtained by co-crystallation and ion gelation [97].

Research by Ben-Othman et al. [65] confirmed, that spray drying with oilseed proteins as a carrier protected the bioactive components of aronia in plant powders, which were characterized by a high FRAP content (>2.5 mmol Fe^{2+}/g) and very good storage stability. The effect of the drying method on the content of bioactive compounds in aronia has been confirmed by Zhang et al. [52]. These studies showed that the optimization of the drying process using ultrasound and microwaves in the presence of calcium ions increases the final polyphenol content by 38% compared to traditional convection drying

Proper selection of technology (e.g. freeze-drying, microencapsulation, co-crystallining) allows for the preservation of bioactive ingredients even above 90%, which makes aronia extracts a promising functional ingredient with high antioxidant efficiency.

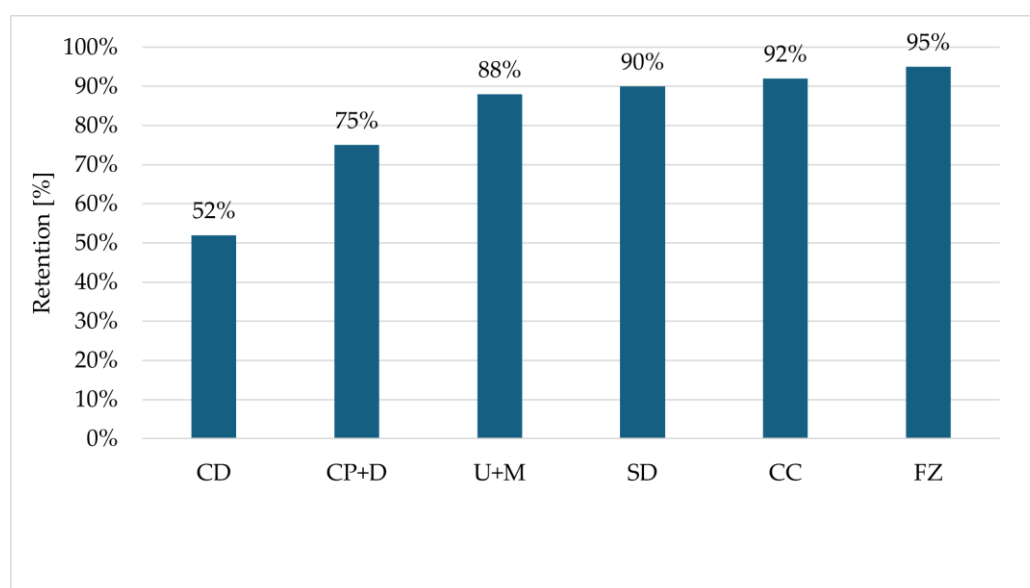


Figure 2. Retention of phenolic compounds (%) in aronia extracts depending on the processing technique used. In-house data based on a literature review [25,52,64]. CD – Convection drying; CP+D – Cold Plasma pre-

treatment + Drying; U+M – Ultrasound + microwaves; SD – Spray Drying (Microencapsulation); CC – Co-Crystallization; FZ – Freeze Drying.

Black chokeberry extracts added to functional foods, in addition to health-promoting benefits and improving technological properties, can affect the sensory properties of the product – both positively and negatively. Features such as color, taste, aroma, texture and general acceptability are extremely important for the consumer, which translates into the market success of a given product. Therefore, sensory analysis is an important part of the evaluation of innovative products with aronia extracts [87].

A visually attractive and vivid colour is the key elements determining the acceptance of a product by consumers. The high content of anthocyanins in black chokeberry fruits (mainly cyanidin-3-galactoside) means that products with the addition of these fruits are characterized by an intense purple-violet color, which is usually positively received and evaluated by consumers. In the study of Samborska et al. [100], apple slices were subjected to the process of osmotic dehydration using a solution consisting of 65°Brix of sucrose and 15% aronia juice concentrate (S65-Ch15 determination). Apples dehydrated with aronia concentrate scored the highest sensory scores in all aspects assessed – color, taste, aroma and overall product quality – compared to the control group treated with only a 65°Brix solution of sucrose without the addition of fruit concentrate.

The usefulness of aronia extracts as food colorants was studied also by Ghendov-Mosan et al. [89], where aronia extract concentrate was used as a natural dye in the production of gummies. Its colouring efficiency was analysed in comparison with synthetic dyes (E131, E162). It was assessed that its coloring efficiency is similar to that of control dyes, with a higher assessment of color attractiveness (average 8.2 out of 9 points). In addition, the use of aronia extract made it possible to increase the antioxidant activity of the gummies (ORAC + 65%).

The introduction of chokeberry extract into the matrix of improved food products results in an astringency increase in the final product, which is due to the characteristics of the fruit of this species. It is mainly due to the presence of procyanidins and tannins, and the presence of these compounds is less accepted in products of liquid and semi-liquid consistency, e.g. in beverages. This is a huge technological challenge in the sensory context. In the study by Petković et al. [98], it was found that beverages that contain more than 15% by volume of aronia juice are too tart and bitter, which resulted in a reduced overall taste experience by more than 25% compared to samples with lower concentrations. For comparison, in the study by Habschied et al. [99], a drink based on barley wort with the addition of aronia juice was produced. Beverages were produced that contained 10%, 20% and 30% chokeberry juice. The best sensory results were obtained for the juice with the highest juice content, i.e. 30%. In order to improve the recipe, it was decided to add peppermint oil and saturate CO₂. Such a drink received a high score of 8.4 on a 10-point hedonic scale. This study proves that the use of synergistic ingredients (e.g. mint) effectively alleviates the negative sensory aspects of aronia.

In the case of aronia extracts dosed into supplemented products in solid form, it significantly affects the texture of the product. Aronia powders, microcapsules and pomace typically increase the density, viscosity and structure of the matrix. The study by Żbikowska et al. [84] showed that muffins in which wheat flour was replaced with chokeberry pomace flour in an amount not exceeding 10% were characterized by an increase in hardness by 12%, but despite this, the overall acceptability of the texture remained at a high level (average 7.3/9 points). Much better results were obtained for gluten-free baking, which suggests the possibility of using powdered chokeberry pomace in the production of gluten-free baked goods. Gluten-free baked goods with the addition of 10% aronia pomace were characterized by more favorable texture properties (m.in. lower hardness and better moisture), larger baking volume and higher sensory ratings compared to their gluten counterparts with 10% addition of aronia pomace. Also Szajnar et al. [91] indicated the positive effect of dry aronia extract usage as food component. It was proved that in fermented dairy products (based on sheep's milk), the addition of aronia fiber increased the density and viscosity of the product, which was positively assessed – the average sensory acceptance was 8.1 on a 9-point scale.

The addition of black chokeberry in the form of juices or extracts also enriches the aroma profile of food products. Masztalerz et al. [80] conducted an analysis of the profile of volatile aromatic compounds in dried apples subjected to the process of osmotic dehydration in chokeberry-mint solution. An increase in the content of aldehydes and esters responsible for fruity and fresh notes was demonstrated, which correlated with a higher aroma rating in the expert panel's assessment.

7. Conclusions

Black chokeberry extracts are a promising ingredient of functional food, exhibiting a wide spectrum of health-promoting and technological properties. Research conducted in the last decade has shown that their use in food products allows to increase antioxidant activity, extend shelf life and improve the visual attractiveness of fortified products. Despite the health benefits of this species, the specific, tart taste of the fruit remains a challenge, limiting its acceptance. Therefore, the key challenge remains to optimize the processing technology in terms of sensory composition.

Since products offered to the market in the functional food category must have above-average characteristics with documented health benefits, parallel research is focused on the development of extraction methods that will minimize the degradation of health-promoting compounds, while ensuring high process efficiency and quality of the final product.

The available literature indicates that the development of aronia berry extract stabilization techniques (e.g. microencapsulation, co-crystallizing, osmotic techniques) and synergistic combinations with other plant components can increase the bioavailability and stability of bioactive compounds, while minimizing unfavorable taste characteristics. Black chokeberry is therefore a promising ingredient in the design of functional foods, but its successful implementation requires further technological, clinical and sensory research. In order to make the potential of aronia species utilized, extremely important seem to identify individual application, where groups of phytochemicals could be bioactive without adverse quality sensation.

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