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Physicochemical, Functional and Nutritional Characteristics of Various Types of Fruit Pomace

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Abstract

The aim of this study was to evaluate and compare dried apple (A), chokeberry (C), grape (G), raspberry (R), and red currant (RC) pomace as potential additives to food, beverages, and cosmetics. Their physicochemical properties and nutritional composition were examined. The fruit pomace was characterised by significant differences in acidity ranging 1.41 (G) to 7.96 g·100 $g^{-1}_{d.w.}$ (R), water holding capacity (2.36–4.25 $g \cdot g^{-1}$, C-A), and oil holding capacity (1.86–2.41 $g \cdot g^{-1}$, C-G). The colour parameters of the pomace differed significantly. The highest lightness L^* was recorded for the apple pomace (66.29). Samples RC and R were characterised by the highest redness (32.99; 26.76), while A, G, and R showed high b^* values, amounting to 28.54, 22.84, and 20.40 (yellowness), respectively. The highest protein (13.01%), fat (6.82%), and fibre (67.38%) contents were recorded in the redcurrant pomace. The mineral analysis revealed high potassium, phosphorus, and calcium contents in all pomace samples, with the grape and redcurrant pomace containing the highest mineral content. These results highlight the potential of fruit pomace as a sustainable, nutritionally enriching ingredient, primarily for food products, and the potential to reduce food waste.

Keywords: fruit pomace; functional properties; dietary fibre; colour parameters; minerals; food sustainability

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1. Introduction

Contemporary challenges related to sustainable development and the need to reduce the negative impact of industry on the environment are driving the search for new solutions in the circular economy [1]. In the context of the agri-food industry, the zero-waste concept, which aims to reuse by-products generated during fruit and vegetable processing [2,3], is of particular interest. Every year, fruit processing generates enormous amounts of waste [4], such as pomace, peel, pits, and seeds, which are often treated as waste or used as animal feed. These residues pose a serious environmental and economic problem due to their mass production and low utilisation [5,6]. It is estimated that the global production of fruit pomace, which arises mainly as a by-product of juice and wine processing, reaches several million tons per year, with apple, citrus, and grape pomace constituting a significant portion [7]. Due to their high moisture content and the presence of easily fermentable organic compounds, the improper storage of such biomass can lead to methane and other greenhouse gas emissions as well as water and soil contamination [8]. Given their specific composition, these residues

require appropriate management technologies to minimise their environmental impact [9]. From a Life Cycle Assessment (LCA) perspective, the environmental impact of fruit pomace processing methods varies. Studies have shown that anaerobic digestion (AD), compared to composting, significantly reduces global warming potential, eutrophication, and acidification impacts [8]. Fruit pomace also remains economically underutilised, despite containing valuable bioactive compounds, such as polyphenols, flavonoids, and dietary fibre. These compounds can be recovered and used as functional ingredients in the food, cosmetic, and pharmaceutical industries. Modern water-based extraction methods (e.g., microwave-assisted or ultrasound-assisted extraction) improve recovery efficiency while reducing the use of organic solvents and the environmental impact of the processes [10]. For instance, grape pomace is rich in anthocyanins and tannins, which are currently being extensively studied for applications in nutraceuticals and in the cosmetic and food industries [11]. Growing sustainability requirements and regulatory pressures are driving the development of comprehensive fruit pomace valorisation systems within a circular economy framework, enabling both the reduction of environmental burdens and the generation of added value [12]. Importantly, many fruit wastes, which are commonly considered low value, can be more valuable than some traditional products, such as juices or jams. By-products are richer in phytochemicals, antioxidants, and antimicrobials than the final products [13]. Numerous studies indicate that the antioxidant activity of citrus peel exceeds that currently found in the fruit pulp itself, highlighting its enormous potential as a valuable, yet still underutilised, raw material in the production of functional foods and nutraceuticals [14–16]. Other studies show that carrot peels contain approximately 50% more β-carotene than the pulp [17]. Pineapple by-products contain a greater amount of phenolic molecules than fresh pulp and are rich in bioactive components, such as vitamin C and carotenoids [18]. Fruit pomace contains significant amounts of vitamins, polyphenols, fibre, and other compounds that have the potential to become valuable raw materials for the production of functional foods, dietary supplements, and cosmetics and pharmaceutical products.

To minimise the environmental burden associated with this waste while simultaneously increasing its value, interest in valorising by-products of fruit and vegetable processing has significantly increased [19]. Research confirms that fruit residues, including pomace and peel, are an excellent source of valuable components, such as proteins, dietary fibre, lipids, minerals, vitamins, and bioactive compounds, e.g., phenolic acids, flavonoids, anthocyanins, carotenoids, and pigments [6,13,19–21]. Their recovery and reuse open new perspectives for various industries, including the food, cosmetics, and pharmaceutical industries, supporting the development of a circular economy [1,13,20,22,23]. Berry pomace, such as chokeberry, raspberry, redcurrant, as well as apple and grape pomace, is particularly promising in terms of its functional and nutritional properties. These products, although often treated as waste, contain significant amounts of soluble and insoluble dietary fibre, which can act as prebiotics, stimulating the growth of beneficial intestinal bacteria and the production of short-chain fatty acids, including butyric acid [24–27]. SCFAs are the main microbial metabolites produced through the fermentation of dietary fibre by anaerobic bacteria in the colon. The three principal SCFAs—acetate, propionate, and butyrate—play crucial roles in maintaining gut health. They exhibit anti-inflammatory, anti-carcinogenic, and antimicrobial properties, help regulate the immune system and the gut microbiota, and support the integrity of the intestinal epithelial barrier. Recent studies also highlight their therapeutic potential in the management of obesity, diabetes, dyslipidaemia, inflammatory bowel diseases (IBD), and cardiovascular disorders [28]. Among them, butyric acid (butyrate) is particularly important due to its unique physiological functions. It serves as the primary energy source for colonocytes—epithelial cells lining the colon—covering up to 70–80% of their energy needs. Butyrate also plays a key role in

maintaining epithelial barrier integrity, modulating gene expression via histone deacetylase (HDAC) inhibition, and reducing pro-inflammatory signalling. Furthermore, the presence of natural antioxidants can extend the shelf life of food products and protect the body against oxidative stress [26,29]. Moreover, the presence of natural antioxidants, such as polyphenols, flavonoids, and phenolic acids, can extend the shelf life of food products by inhibiting lipid oxidation and the degradation of pigments and vitamins. These compounds act as free radical scavengers and metal ion chelators (e.g., iron, copper), which initiate radical reactions responsible for the deterioration of the sensory and nutritional quality of food [30,31]. The addition of natural antioxidants may also limit the growth of microorganisms, further extending product shelf life [32]. In the human body, plant-derived antioxidants support the endogenous antioxidant defence system (e.g., enzymes such as SOD, catalase, and glutathione peroxidase) by neutralising reactive oxygen species (ROS), which are generated by environmental stress, UV radiation, pollution, or inflammation. These compounds protect cells from damage to membrane lipids, proteins, and DNA, thereby reducing the risk of developing chronic diseases, such as atherosclerosis, cancer, type 2 diabetes, or neurodegenerative disorders [33,34].

With appropriate pre-processing methods, such as drying, grinding, or freeze-drying, it is possible to transform pomace into powders with high nutritional and functional value. Such ingredients can be used in the baking, dairy, and meat industries, not only as additives improving the nutritional and functional profile of food, but also as natural substitutes for synthetic ingredients. Beyond the food sector, pomace can be used in the production of feed, cosmetics, biofuels, packaging materials, and even bioplastics [2]. Recently, numerous studies have been conducted on the use of fruit pomace for food fortification [35–42]. This concept is fully justified, considering the health-promoting value of these by-products. However, it should be noted that fruit pomace typically has different properties than commonly used food raw materials. Therefore, fortification of cereal or dairy products with plant residues can result in significant changes in the acidity, consistency, or colour of the finished product [26,35,43]. Functional properties such as water holding capacity, swelling capacity, and oil holding capacity may also change. These parameters of significant importance from both a technological and physiological perspective. They play a key role in the effective use of pomace as a food ingredient, influencing its texture and recipe stability. Moreover, these properties are particularly important in a health-promoting context because they contribute to the hypoglycaemic and hypolipidaemic effects of fibre-rich food ingredients [44].

The aim of this study is to evaluate the functional, nutritional, and physicochemical properties of pomace from chokeberries, apples, grapes, raspberries, and redcurrants. As part of the study, physicochemical and functional parameters such as acidity, water absorption, oil absorption, and colour were determined. The chemical composition was also analysed, including protein, fat, ash, dietary fibre, carbohydrates, and minerals. These results will allow assessment of the potential use of the analysed pomace as functional ingredients in the food industry and contribute to its effective valorisation in the spirit of the circular economy.

2. Materials and Methods

2.1. Research Material

The fruits used in this study were purchased from Lubelski Rynek Hurtowy S.A., Poland. The research material consisted of fruit pomace. The processed fruit varieties included apple Champion, chokeberry Galicjanka, grape Nero, raspberry Polesie, and red currant Dutch Red (Figure 1). The fruit was pressed using a slow-speed press (Sana EUJ-707, Omega Products, České Budějovice, Czech Republic). The obtained pomace was dried in a

convection oven (Houno, DK 8940, Ronders, Danmark) at 60 °C to obtain moisture content <10%. Before further analysis, the pomace was ground using a laboratory mill (Chemland, FW100, Stargard, Poland) and sieved through a 0.2 mm stainless steel sieve. The pomace was stored in tight polyethylene bags at 4 ± 1 °C.

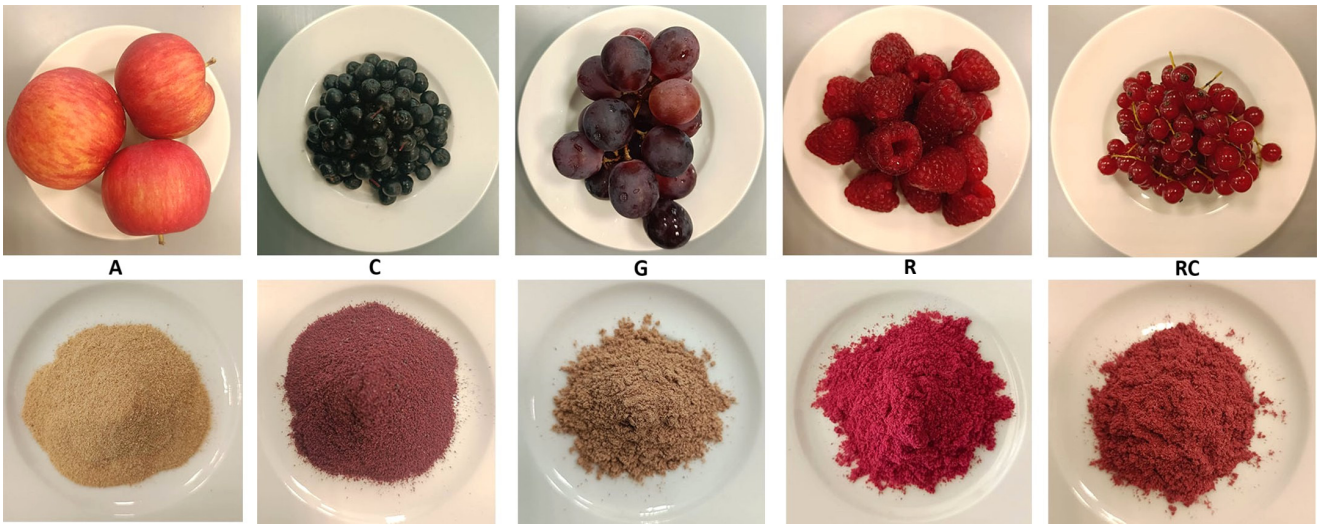


Figure 1. Fruits (**top**) and the corresponding pomace samples (**bottom**) analyzed in this study. A—apple, C—chokeberry, G—grape, R—raspberry, RC—redcurrant.

2.2. Reagents

All reagents used for chemical analyses were of analytical grade. Sodium hydroxide was purchased from Alfachem (Poznań, Poland). K-RINTDF enzymatic kits from Megazyme (Wicklow, Ireland) were used for dietary fiber analysis. Reagents used for protein and fat determination were purchased from: sulfuric acid—StanLab (Lublin, Poland), hydrochloric acid—AlfaChem (Poznań, Poland), and petroleum ether—POCH (Gliwice, Poland), respectively.

2.3. Determination of Physicochemical and Functional Properties

The test for each parameter was performed in 3 repetitions.

Moisture content was measured following the procedure described in [45]. Samples were dried in a laboratory dryer (POL-EKO Aparatura, model SLN 15 STD, Wodzisław, Poland) at temperatures not exceeding 105 °C.

Total Titratable Acidity (TTA) was assessed according to the official AOAC method 942.15 [46] using a glass electrode. The results was calculated considering citric acid as the dominant organic acid for chokeberry, raspberry and red currant pomace, malic acid as the dominant acid for apple pomace and tartaric acid for grape pomace.

The content of total soluble solids (TSS) was determined by mixing 1 g of a dried sample with 9 g of distilled water. The mixture was shaken for 1 min using a shaker (ELMI Ltd., Riga, Latvia). Afterwards, the suspension was centrifuged at 3000 rpm for 15 min (MPW-260R, MPW Med. Instruments, Warsaw, Poland) to separate solid residues. The clear supernatant obtained was then analysed for TSS using an electronic refractometer (LLG-uniREFRACTO, Meckenheim, Germany) according to the method described in [47].

Water holding capacity (WHC), swelling capacity (SC), and oil holding capacity (OHC) of the fruit pomace were determined according to the procedures described by Jurevičiūtė et al. [44] with minor modifications.

Water holding capacity (WHC) was evaluated by preparing a suspension of 1 g of powdered sample mixed with 10 millilitres of distilled water. The mixture was allowed to

hydrate at room temperature for 24 h, followed by centrifugation at 3000 rpm for 15 min. After carefully decanting the supernatant, the remaining sediment was weighed. WHC was expressed as the ratio of the weight of the hydrated gel to the initial weight of the dry sample:

$$WHC\left(\mathrm{g}\cdot\mathrm{g}^{-1}\right) = \frac{(m_2 - m_1)}{m_1} \quad (1)$$

where m_1 is the mass of the dry sample (g) before hydration, and m_2 is the mass of the sample (g) after hydration.

Swelling capacity (SC): A 0.5 g sample (M) was weighed into a 15 mL graduated conical tube, and the volume was recorded as V_1 (mL). The sample was then mixed with 10 mL of distilled water. After mixing, the mixture was allowed to equilibrate at room temperature for 24 h, and the bed volume was recorded as V_2 (mL). SC was calculated using Formula (2):

$$SC\left(\mathrm{mL}\cdot\mathrm{g}^{-1}\right) = \frac{(V_2 - V_1)}{M} \quad (2)$$

Oil holding capacity (OHC) was determined by mixing 1 g of the sample with 10 millilitres of sunflower oil in a centrifuge tube, followed by incubation at 37 °C for 1 h. After incubation, the mixture was centrifuged at 3000 rpm for 15 min (MPW-260R, MPW Med. Instruments, Warsaw, Poland), and the supernatant was carefully discarded. The weight of the pomace after oil absorption was then measured, and OHC was calculated using Formula (3):

$$OHC\left(\mathrm{g}\cdot\mathrm{g}^{-1}\right) = \frac{M_2 - M_1}{M_1} \quad (3)$$

where M_1 is the mass of the sample (g) before incubation with oil, and M_2 is the mass of the sample (g) after incubation with oil.

2.4. Measurement of Colour Parameters

The colour analysis of the fruit pomace was conducted using a 3Color SF80 Spectrophotometer (Marcq-en-Barœul, France). The measurements were taken with a D65 light source, a 10° observer angle, and an 8 mm aperture in the measuring head. The following CIE colour parameters were recorded: L^*, representing lightness, where values between 0 and 50 correspond to dark colours, and values from 51 to 100 indicate light colours; a^*, which describes the colour axis from green (negative values) to red (positive values); and b^*, representing the colour axis from blue (negative values) to yellow (positive values). Each measurement was repeated 10 times to ensure accuracy.

Chroma (C^*) was calculated using Formula (4) [48]:

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \quad (4)$$

2.5. Determination of the Chemical Composition

The test was performed in 3 replicates for each type of pomace. The chemical composition was determined in accordance with AACC standards [45]:

Protein content (AACC, method 46-10.01) was determined using a Kjeltec apparatus (TM8400, Foss, Mulgrave, Australia). Distillation was performed in an automatic Kjeltec Auto set by Tecator.

Fat content determination (AACC, method 30-10.01) was conducted by continuous extraction with ether using a Soxtec (TM8000) apparatus.

Ash content analysis (AACC, method 08-01.01): the determination of the ash content consisted in complete combustion of the material and roasting the ash in a muffle furnace (LAC Ltd., M: LE 18/11, Rajhard, Czech Republic).

Dietary fibre content: the determination was carried out according to the weighing method in accordance with the PN-A-79011-15:1998 standard [49]. The analysis consisted of digesting the test sample with thermostable α-amylase, pepsin, and pancreatin enzymes and then determining the undigested residue of insoluble dietary fibre and soluble dietary fibre by weight after precipitation from the supernatant solution.

Carbohydrate content (C) was calculated from the difference: 100 − (weight in grams [protein + fat + TDF + ash] in 100 g of dry matter.

2.6. Determination of Element Content

Three grams of dried pomace were compressed into pellets using a 25-ton hydraulic press (Fuji, Model 181-1375, Madison, WI, USA). The elemental composition of the resulting pellets was analysed using an EDX-8100P X-ray fluorescence spectrometer (Shimadzu, Kyoto, Japan). All measurements were conducted in triplicate [50].

2.7. Statistical Analysis

The test results were subjected to analysis using the Statistica 13 software package (StatSoft Inc., Tulsa, OK, USA). The numerical values were subjected to one-way analysis of variance (ANOVA). The significance of the observed differences was verified by Tukey's test, with a significance level of $\alpha = 0.05$.

3. Results and Discussion

3.1. Physicochemical Properties of Fruit Pomace

Table 1 presents the physicochemical properties of the analysed fruit pomace. The moisture content of the fruit pomace determined immediately after pressing was 60.73–65.10%. Significantly the lowest values were recorded for the redcurrant pomace. The moisture content of the remaining samples did not differ significantly. The obtained results are consistent with previous studies. Kaloudi et al. [51] reported that the moisture content of chokeberry pomace was 66.7%, Spinei & Oroian [52] found that the moisture content of grape pomace ranged from 50% to 72%, depending on the grape variety and degree of ripeness. As reported by Jung et al. [53], the initial moisture content of apple pomace was as high as 80%. It is therefore necessary to dehydrate the pomace, which will not only reduce the mass of the by-product but will also inhibit the growth of microorganisms, extending the storage time and shelf life [54].

Table 1. Physicochemical properties of the fruit pomace.

Sample	Moisture After Pressing [%]	Moisture After Drying [%]	TTA [g·100 g^{-1}$_{d.w.}$]	TSS [°Brix]
A	64.99 ± 0.85 ^{a}	6.73 ± 0.13 ^{d}	1.62 ± 0.05 ^{c}	5.43 ± 0.05 ^{a}
C	64.06 ± 0.08 ^{a}	8.13 ± 0.18 ^{b}	3.52 ± 0.01 ^{b}	1.00 ± 0.08 ^{e}
G	65.10 ± 1.11 ^{a}	7.26 ± 0.15 ^{cd}	1.41 ± 0.52 ^{c}	4.30 ± 0.00 ^{c}
R	63.86 ± 0.58 ^{a}	9.55 ± 0.37 ^{a}	7.96 ± 0.27 ^{a}	4.50 ± 0.00 ^{b}
RC	60.73 ± 0.54 ^{b}	7.77 ± 0.07 ^{bc}	4.21 ± 0.08 ^{b}	2.03 ± 0.05 ^{d}

A—apple pomace, C—chokeberry pomace, G—grape pomace, R—raspberry pomace, RC—redcurrant pomace. TTA—total titratable acidity. TSS—total soluble solids. The presented numbers represent the arithmetic mean of the measurements ($n = 3$) ± SD; a different letter in the rows indicates that the presented values were significantly different (Tukey test).

After drying, the moisture content in all the pomace types was below 10%. The raspberry pomace (R) had the highest moisture content at 9.55%. The apple pomace (A) had the lowest moisture content at 6.73%. No statistically significant differences in the moisture content were found for the apple and grape pomace, the chokeberry and redcurrant pomace, or the grape and redcurrant pomace.

The moisture content of fruit pomace depends primarily on the drying time and method as well as the initial moisture content of the material. For example, Lyu et al. [55] found that the moisture content of apple pomace ranged from 4.4% to 10.5%. A study conducted by Sharma et al. [56] indicated that fibres formed after drying apple pomace had a moisture content of approximately 15.64% and retained good hygroscopic properties even after 6 months of storage. This means that a moisture level below 16% can be considered safe, at least in terms of maintaining functional properties.

In contrast, the grape pomace powder used by Sant'Anna et al. [57] was dried to a moisture content of 8.8 ± 0.9%. The results suggest that the grape pomace powder was microbiologically safe against pathogenic bacteria during 6 months of storage at ambient conditions. However, the authors noted that, with prolonged storage, the product may degrade due to the growth of yeasts and other spoilage microorganisms. It should also be noted that the total polyphenol content and antioxidant activity of pomace stored at room temperature remained stable for 150 days. However, a decrease in anthocyanin content was observed after 90 days of storage.

The highest value of titratable acidity (7.96 g·100 $g^{-1}_{d.w.}$) was found in the raspberry pomace, while the lowest level was determined in the grape pomace (1.41 g·100 $g^{-1}_{d.w.}$). In the case of the apple and grape pomace, no statistically significant differences were found. For apple pomace, similar titratable acidity results (1.83%) were obtained by Gouw et al. [47]. The authors also noted significantly lower values for other berries. For raspberries, the titratable acidity was 0.43%. In contrast, in a study conducted by Jin et al. [58] on red grape pomace, titratable acidity ranged from 3.08 to 3.60% (depending on the cultivar).

Organic acids are closely related to total acidity. This parameter can be of great importance for food fortification processes. The more acids, the higher the TTA value and the lower the pH of the resulting products with added fruit pomace. For example, the pH of kefir enriched with raspberry pomace decreased from 4.92 (control sample) to 4.44 (20% raspberry pomace) [43]. Analogous changes were observed for bakery products—in a study conducted by Pecyna et al. [59], the addition of 10% dried raspberry pomace resulted in a more than threefold increase in the acidity of the resulting gluten-free bread.

The highest content of soluble substances was observed for the apple pomace. Samples G and R were characterised by slightly lower TSS values. The lowest values were definitely recorded for the chokeberry pomace. In a study reported by Gouw et al. [47], which analysed the properties of pomace from four different fruits, the highest TSS values were observed for apple pomace as well.

3.2. Functional Properties of Fruit Pomace

Table 2 presents the functional properties of the analysed fruit pomace. Statistically significant differences were observed for water holding capacity (WHC). The apple pomace had the highest WHC (4.25 g·g^{-1}), while the chokeberry pomace had the lowest value of this parameter (2.36 g·g^{-1}). Similar results regarding the WHC of raspberry pomace were obtained by Li et al. [60]. The authors analysed the properties of defatted raspberry pomace. However, it can be noted that the oil capacity reported by Li et al. [60] was higher, which could probably be related to the initial lower fat content in the material. As shown by Nemetz et al. [61], on the other hand, chokeberry pomace powders achieved a water-binding capacity of 2.43 g·$g^{-1}_{d.w}$ after 24 h. In the case of redcurrant pomace, the water-binding capacity was 4.06 g·$g^{-1}_{d.w.}$, while chokeberry pomace had a water-binding capacity of 3.85 g·$g^{-1}_{d.w.}$ [62].

Table 2. Functional properties of the fruit pomace.

Sample	WHC [g·g^{-1}]	SC [mL·g^{-1}]	OHC [g·g^{-1}]
A	4.25 ± 0.08 ^{a}	6.54 ± 0.16 ^{a}	1.89 ± 0.02 ^{c}
C	2.36 ± 0.04 ^{e}	1.57 ± 0.01 ^{d}	1.86 ± 0.04 ^{c}
G	3.63 ± 0.12 ^{b}	1.79 ± 0.01 ^{c}	2.41 ± 0.01 ^{a}
R	2.63 ± 0.01 ^{d}	2.80 ± 0.00 ^{b}	1.91 ± 0.01 ^{c}
RC	3.12 ± 0.03 ^{c}	1.58 ± 0.01 ^{d}	2.03 ± 0.02 ^{b}

A—apple pomace, C—chokeberry pomace, G—grape pomace, R—raspberry pomace, RC—redcurrant pomace. WHC—water holding capacity, SC—swelling capacity, OHC—oil holding capacity. The presented numbers represent the arithmetic mean of the measurements (n = 3) ± SD; a different letter in the rows indicates that the presented values were significantly different (Tukey test).

The apple pomace had the highest swelling capacity (SC) at 6.54. In contrast, the chokeberry pomace had the lowest value of this parameter. No statistically significant differences were found for the swelling capacity of the chokeberry and redcurrant pomace. In a study conducted by Nemetz [61], the swelling capacity of chokeberry pomace powders was slightly higher than in our study, at 5.08 mL·g$^{-1}_{\text{d.w.}}$ Similarly, in another study, the swelling capacity for chokeberry pomace was recorded at 6.70 mL·g$^{-1}_{\text{d.w.}}$ and for redcurrant pomace at 6.12 mL·g$^{-1}_{\text{d.w.}}$ [62]. The different results may be due to slight differences in methodology. In the study by Gouw et al. [47], similar trends were observed as in our study. Apple pomace was characterized by the highest swelling capacity (approximately 6.5 mL·g$^{-1}_{\text{d.w.}}$). Similar results were also recorded for raspberry pomace, SC was slightly below 3.0 mL·g$^{-1}_{\text{d.w.}}$·

A significant functional parameter of the fruit pomace studied was its oil holding capacity (OHC). The grape pomace had the highest OHC value of 2.41 g·g^{-1}. The high SDF content in the grape pomace may have contributed to the increase in OHC [63]. The chokeberry pomace had the lowest level (1.86 g·g^{-1}). No statistically significant differences in oil capacity were found for the apple, chokeberry, and raspberry pomace. Gouw et al. [47] noted that the oil adsorption capacity for apple and raspberry pomace did not exceed 1.5 g·g^{-1}. The authors observed higher values of the tested parameter for blueberry and cranberry pomace. In turn, the results obtained for chokeberry pomace by Nemetz et al. [61] were also similar to those in our study—the oil absorption capacity was 1.74 g·g^{-1}.

The water/oil holding capacity and swelling capacity of powdered fruit remnants indicate the hydration properties of the fiber component [64]. These properties play a key role in imparting the appropriate texture to the final product [65]. For example, adding orange fiber to Bolognese sausages affected juiciness but did not alter the saltiness, fattiness, or residual flavor of the sausages [66]. Water-soluble fibers can also positively influence emulsion stabilization. Orange pulp has been shown to be a suitable raw material as a natural emulsifier [67]. Orange residue powders can generally improve physical and functional properties, characterized by greater water and oil holding capacity and, therefore, better emulsification capacity. Orange fiber obtained from pomace is a good emulsifier due to its higher surface activity and apparent viscosity [67]. Kieserling et al. [68] demonstrated that fine orange fibers (especially at high concentrations) effectively stabilize yogurt gels. The authors explain that high methoxylated pectin stabilizes the casein network by bridging.

Colour of the Fruit Pomace

Colour is one of the key indicators of sensory quality in food, as it significantly determines consumers' perception of a product and influences their purchasing decisions. Therefore, the assessment of colour parameters plays a fundamental role in food technol-

ogy, especially in the context of quality control and prediction of the acceptability of the final product.

Table 3 presents the results of the colour analysis of individual fruit pomace samples. Statistically significant differences were observed in the lightness (L^*) of individual pomace samples. The highest lightness (L^*) value was recorded for the apple pomace (66.29), while the lowest value was found for the chokeberry pomace (18.68).

Table 3. Colour parameters of the fruit pomace.

Sample	L^*	a^*	b^*	C^*
A	66.29 ± 0.85^{a}	9.05 ± 0.52^{e}	28.54 ± 0.60^{a}	29.95 ± 0.60^{c}
C	18.68 ± 0.79^{e}	11.66 ± 0.28^{d}	6.78 ± 0.29^{e}	13.48 ± 0.36^{e}
G	48.01 ± 0.91^{b}	12.82 ± 0.54^{c}	22.84 ± 1.63^{b}	26.20 ± 1.43^{d}
R	42.65 ± 0.85^{c}	26.76 ± 0.49^{b}	20.40 ± 1.51^{c}	33.66 ± 1.07^{b}
RC	38.66 ± 0.66^{d}	32.99 ± 0.64^{a}	12.08 ± 0.37^{d}	35.13 ± 0.71^{a}

A—apple pomace, C—chokeberry pomace, G—grape pomace, R—raspberry pomace, RC—redcurrant pomace. The presented numbers represent the arithmetic mean of the measurements (n = 10) ± SD; a different letter in the rows indicates that the presented values were significantly different (Tukey test).

The lowest value of the a^* parameter (indicating the intensity of the red colour) was recorded for the apple pomace (9.05). The highest a^* values were recorded for the redcurrant pomace (32.99) and the raspberry pomace (26.76). Statistically significant differences were found in the a^* parameter values between the analysed fruit pomace. However, the a^* parameter values for all tested samples were positive, indicating reddening of the material.

The highest b^* parameter value (indicating the intensity of the yellow colour) was recorded for the apple pomace (28.54), while the remaining fruit pomace samples tested had significantly lower b^* values, but these values were positive for all by-products. Statistically significant differences were observed for the intensity of the yellow colour.

Statistically significant differences were found in the chrominance (C^*) level between the analysed fruit pomace samples, indicating variability in colour saturation. The chrominance (degree of colour saturation) (C^*) had the highest value for the redcurrant pomace (35.13), while the lowest value was recorded for the chokeberry pomace (13.48).

Similar colour trends for chokeberry, blackcurrant, and apple pomace were also noted by Pakulska et al. [69], who observed the highest level of lightness L^* in apple pomace (57.35), with the lowest values of this parameter obtained for chokeberry (36.54) and blackcurrant (37.71) pomace. In a study conducted by Pakulska et al. [69], the highest red colour intensity (parameter a^* value) was observed for blackcurrant pomace, while the lowest values of this parameter were recorded for chokeberry pomace, reaching 8.53. In turn, the highest share of the yellow component (parameter b^*) was found for apple pomace (21.81), while chokeberry and blackcurrant pomace were characterised by lower values of this parameter—4.38 and 3.91, respectively. The observed differences in the L^*, a^* and b^* colour parameters may result from the variety and degree of ripeness of the fruit from which the plant material was obtained.

In turn, in a study of fruit pomace and jams made from such pomace conducted by Kapoor et al. [41], the colour parameters of apple pomace were as follows: lightness (L^*)—43.84, redness (a^*)—4.73, while yellowness (b^*) significantly differed from the results obtained in our study and amounted to 2.78. Kapoor et al. [41] report that the lower L^* value in the case of apple pomace indicates slight browning caused by polyphenol oxidase or peroxidase enzymes during juice processing, while the value of the a^* parameter may result from the red-brown colour of apple skin in the pomace. In turn, the jam produced from this apple pomace had a brightness similar to the brightness of the pomace itself—L^* 42.19, the a^* parameter increased to the value of 8.99, while the b^* parameter of apple jams was 10.48.

Numerous studies have shown that the use of fruit-based ingredients, such as fruit flour or pomace, significantly affects the colour properties of bakery products. Petković et al. [70] observed a decrease in the b^* parameter in bread enriched with chokeberry flour, while Rocha-Parra et al. [71] showed that the addition of pear pomace led to a noticeable darkening of sponge cakes and layer cakes. Similar results were obtained by Kruczek et al. [72], who replaced corn flour with apple pomace in various concentrations (15–60%) and observed significant changes in the colour of baked goods. The authors attributed these changes to the presence of natural and dietary fibre contained in the fruit additives, with a dominant role of red pigments—mainly cyanidin derivatives—in shaping the final colour of the products [73]. Additionally, other studies confirm that various fruit pomace types—including those derived from sour cherry, raspberry, chokeberry, or peach—can significantly alter the colour profile and visual appeal of bakery products. Partial replacement of flour with these types of pomace has been shown to result in darker, redder, and more intense colouration in such products as gluten-free breads and muffins [38,74,75]. In addition, berry pomace, a by-product of juice production, has been shown to be a more effective source of anthocyanins and phenolic compounds than whole fruit. The use of low drying temperatures and rapid grinding of the seedless fraction allowed the production of intensely red powders without the use of solvents or complex technological processes. Powders from chokeberries, blueberries, and elderberries demonstrated favourable technical and functional properties, although they may be limited by rapid sedimentation in low-viscosity solutions. Nevertheless, their strong colouring properties, resulting from the high content of natural pigments, make them attractive food additives, particularly in the context of improving and modifying the colour of baked goods [61]. Fruit and vegetable by-products are used as innovative components that increase the nutritional value of bread and baked goods [39].

The influence of fruit components on the colour of raw dough was also extensively described by Zbikowska et al. [74], who demonstrated that the addition of chokeberry pomace significantly affected the colour parameters in both wheat dough and its gluten-free version. Even small amounts of this additive caused statistically significant changes in all analysed colour components—a significant decrease in lightness (L^*) and an increase in red colour saturation (a^*) were observed. In the traditional dough, a decrease in the yellow component (b^*) was also noted, while an increase in the blue colour was observed in the gluten-free dough.

Similar colour effects were reported by Chikpah et al. [76] after using blueberry pomace in cookie production and by Kruczek et al. [72] after adding apple pomace. Pecyna et al. [38] confirmed these observations by analysing the effect of raspberry and chokeberry pomace—both convectively dried and freeze-dried—on the colour of gluten-free bread. Their use resulted in a decrease in lightness (L^*), an increase in red saturation (a^*), and a reduction in the yellow component (b^*), which clearly indicates a significant effect of fruit additions on the colorimetric parameters of bread.

Chrominance (C^*) is a measure of colour saturation and is closely related to its perceived intensity. Treated as a quantitative indicator of colourfulness, it determines the degree of deviation of a given colour from an achromatic reference, which is gray with the same lightness value (L^*). Higher C^* values indicate greater colour saturation, which translates into a stronger perception of colour intensity by the observer [77]. In a study conducted by Szymanowska et al. [77], in which wafers were enriched with freeze-dried raspberry pomace, a decrease in chrominance was observed with an increase in the amount of pomace added. Such trends are also observed for other products with added fruit pomace [38,78].

3.3. Nutritional Properties of the Fruit Pomace

Figure 2 shows the soluble and insoluble dietary fibre content in the fruit pomace. The composition analysis showed a predominance of insoluble dietary fibre in all pomace types, with the redcurrant pomace containing the highest amount of IDF. However, Eksi Karaagac et al. [79] showed that whole redcurrants contain more soluble fibre (4.00 g·100 g^{-1}) than insoluble fibre (3.16 g·100 g^{-1}).

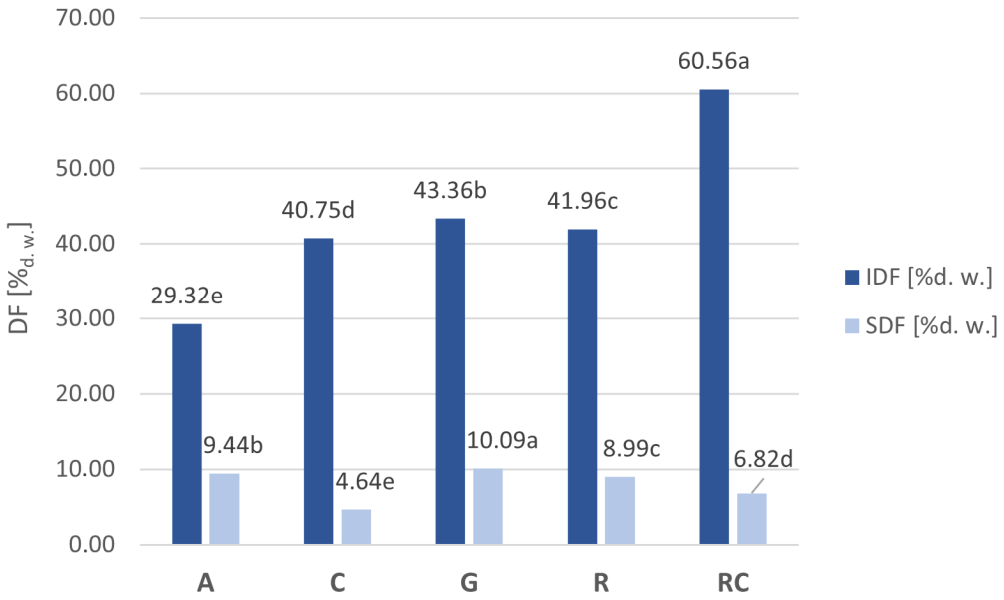


Figure 2. Content of dietary fibre in the fruit pomace. A—apple pomace, C—chokeberry pomace, G—grape pomace, R—raspberry pomace, RC—redcurrant pomace. DF—dietary fibre, IDF—insoluble dietary fibre, SDF—soluble dietary fibre. The presented numbers represent the arithmetic mean of the measurements (n = 3) ±SD; a different letter in the rows indicates that the presented values were significantly different (Tukey test).

Of all the samples analysed, the highest proportion of SDF was found in the apple pomace. Similar IDF and SDF relationships for dried apple pomace were also reported by Gouw et al. [47]. The authors reported that the soluble fibre content ranged from 2.50 to 4.18, depending on the method of determination. Insoluble fibre, on the other hand, accounted for 29.13–29.91%. The ratio of insoluble to soluble fibre was slightly different for raspberry pomace. The IDF content was found to be 0.34–0.41 and the SDF content was 38.13–51.70%. In turn, Tejeda-Miramontes et al. [80] analysed raspberry pomace dried using various methods and at different temperatures. They found that the insoluble fibre content ranged from 56.3 to 61.78%, and the soluble fibre content was in the range from 2.35 to 3.87%. Interestingly, as the temperature increased, the proportion of IDF decreased and the amount of SDF increased.

Insoluble fibre usually occurs in the form of particles that resist penetration by the microbiota of the large intestine, thus playing an important role in cleansing the intestines and supporting healthy large intestine epithelium [81]. On the other hand, soluble fibre can swell or dissolve in water and thus affect the rate of passage, viscosity, and interactions with digestive enzymes and bile salts in the stomach and small intestine. These phenomena slow down many processes related to digestion [39].

Furthermore, the main bacterial metabolites produced by the fermentation of dietary fibre by specific anaerobic bacteria in the large intestine are short-chain fatty acids (SCFAs). The three main SCFAs are butyrate, propionate, and acetate. SCFAs ensure proper intestinal function, exhibit anti-inflammatory, anticancer, and antimicrobial properties, modulate the gut microbiota and immune system, and help maintain the integrity of the intestinal

epithelial barrier. Promising results have been observed for the treatment of obesity, diabetes, lipid disorders, inflammatory bowel disease, and cardiovascular disease [82,83].

When it comes to the food applications of dietary fibre, soluble dietary fibre provides better texture and taste than insoluble dietary fibre and is easy to use in food processing, as it increases the ability to provide viscosity and acts as an emulsifier [84].

Table 4 presents the nutritional properties of the fruit pomace. Statistically significant differences in the protein content were observed in the analysed fruit pomace. The redcurrant pomace had the highest protein content (13.01%$_{d.w.}$), while the apple pomace had the lowest protein content of only 2.91%$_{d.w.}$.

Table 4. Nutritional properties of the fruit pomace.

Sample	Protein [%$_{d.w.}$]	Fat [%$_{d.w.}$]	Ash [%$_{d.w.}$]	Carbohydrates [%$_{d.w.}$]	TDF [%$_{d.w.}$]
A	2.91 ± 0.02 ^{e}	0.92 ± 0.04 ^{e}	2.38 ± 0.04 ^{bc}	56.34 ± 0.18 ^{a}	37.45 ± 0.18 ^{e}
C	4.19 ± 0.06 ^{d}	2.07 ± 0.15 ^{d}	2.13 ± 0.05 ^{c}	49.50 ± 0.08 ^{b}	42.10 ± 0.15 ^{d}
G	7.45 ± 0.04 ^{c}	4.06 ± 0.14 ^{c}	3.71 ± 0.02 ^{a}	34.08 ± 0.25 ^{d}	50.70 ± 0.15 ^{b}
R	8.71 ± 0.05 ^{b}	5.92 ± 0.04 ^{b}	2.70 ± 0.28 ^{b}	35.59 ± 0.13 ^{c}	47.07 ± 0.06 ^{c}
RC	13.01 ± 0.05 ^{a}	6.82 ± 0.03 ^{a}	3.39 ± 0.01 ^{a}	9.39 ± 0.56 ^{e}	67.38 ± 0.53 ^{a}

A—apple pomace, C—chokeberry pomace, G—grape pomace, R—raspberry pomace, RC—redcurrant pomace. TDF—total dietary fibre. The presented numbers represent the arithmetic mean of the measurements (n = 3) ±SD; a different letter in the rows indicates that the presented values were significantly different (Tukey test).

In a study conducted by Jin et al. [58] on red grape pomace, the protein content ranged from 11.5 to 13% (depending on the cultivar). The chemical composition of grape pomace, a by-product of grape processing, exhibits significant variability, determined by a number of factors, including the type of waste generated, the grape variety, agrotechnical conditions, and the raw material processing method used [85]. Antonić et al. [86] indicated that the protein content in grape pomace was 3.57–14.17 g·100 g^{-1}. Kumar et al. [36] found that grape pomace contained 8.49% protein. Apple pomace, as reported by Lyu et al. [55], had from 1.2 to 4.7% protein content. In the study conducted by Kumar et al. [36], the protein content in apple pomace was 4%. As demonstrated by Pieszka et al. [87], the total protein content in dried apple, blackcurrant, and chokeberry pomace was 6.91%, 12.76%, and 10.77%, respectively. Reißner et al. [62] reported that the protein content was 117.6 g·kg$^{-1}{}_{d.w.}$ in redcurrant pomace and 59.7 g·kg$^{-1}{}_{d.w.}$ in chokeberry pomace.

Statistically significant differences were also noted for the fat content of the analysed fruit pomace. The redcurrant pomace had the highest fat content (6.82%$_{d.w.}$), while the apple pomace had the lowest fat content (0.92%$_{d.w.}$)—similar to the protein content. Studies conducted by Lyu et al. [55] confirm that the lipid content in apple pomace is low, ranging between 0.6 and 4.2%. In Antonić et al. [86], the fat content in grape pomace ranged from 1.14 to 13.90 g·100 g^{-1}, while Jin et al. [58] indicated that the lipid content in grape pomace was in the range of 7.19–12.5%. The crude fat level in chokeberry and apple pomace samples studied by Pieszka et al. [87] was 5.15% and 3.30%, respectively. In the work of Reißner et al. [62] the fat content was 142.3 g·kg$^{-1}{}_{d.w.}$ in redcurrant pomace powder and 36.1 g·kg$^{-1}{}_{d.w.}$ in chokeberry pomace.

As regards the ash content, no statistically significant differences were observed between the grape and redcurrant pomace, apple pomace, and chokeberry pomace. The grape pomace had the highest ash content (3.71%$_{d.w.}$), while the chokeberry pomace had its lowest amount (2.13%$_{d.w.}$).

In studies conducted by Reißner et al. [62], the ash content was 26.6 g·kg$^{-1}{}_{d.w.}$ in redcurrant pomace and 19.2 g·kg$^{-1}{}_{d.w.}$ in chokeberry pomace. In contrast, in studies conducted by Jin et al. [58] on red grape pomace of various varieties, which had been freeze-dried and then

ground, the ash content ranged from 4.52 to 6.08% (depending on the cultivar). In a study conducted by Antonić et al. [86], grape pomace contained 1.73–9.10 g·100 g^{-1} of ash, and Kumar et al. [36] reported that the ash content in grape pomace was 4.6%. The ash content in apple pomace was determined at 1.5–2.5% [55], while the ash content reported in [36] ranged from 0.38–1.6%.

Another parameter measured during the study was the carbohydrate content. The highest carbohydrate content was found in the apple pomace, followed by the chokeberry pomace (56.34% and 49.50%), while the redcurrant pomace had the lowest carbohydrate content at 9.39% dry weight.

As reported by Luy et al. [55], the carbohydrate content in apple pomace ranged from 45.1 to 83.8%. In turn, Kumar et al. [36] showed that the carbohydrate content in grape pomace was 29.2% and ranged from 9.5 to 22% in apple pomace. In contrast, in a study conducted by Reißner et al. [62], the carbohydrate content in blueberry pomace powders was 22 $g \cdot kg^{-1}_{d.w.}$ in blackcurrant pomace, 126.5 $g \cdot kg^{-1}_{d.w.}$ in redcurrant pomace, and 288.8 $g/kg_{d.w.}$ in chokeberry pomace.

The total fibre content ranged from 37.45 to 67.38%$_{d.w.}$ The highest values were recorded for the redcurrant pomace. The apple and chokeberry pomace contained the lowest TDF content, although it was still high. Pieszka et al. [87] reported slightly lower crude fibre content: apple pomace 25.69% and chokeberry pomace 21.79%. In contrast, Reißner et al. [62] demonstrated that chokeberry pomace contained a similar amount of fibre as redcurrant pomace—595 $g \cdot kg^{-1}$ and 580.8 $g \cdot kg^{-1}$, respectively.

The high dietary fibre content means that the inclusion of fruit pomace or parts thereof contributes to improving nutritional properties, particularly in terms of dietary fibre content and energy value [40,59,62,88,89].

Studies have shown that the addition of soluble fibre to food effectively reduces the postprandial increase in blood glucose, insulin, and cholesterol levels in humans. This may be particularly important information for manufacturers of starchy products, such as bakery products, as most of them have a high glycaemic response [39].

Elemental compositions are presented in Table 5. The K, P, and Ca elements were present in the highest amounts in all fruit pomace types. Potassium (K), which had the highest share among the analysed elements, is important for water and electrolyte balance, muscle contractions, and nerve function [90]. One of its forms is potassium bitartrate (wine stone), which is produced during fermentation. Although usually present in small amounts, it can be recovered and used in the food and technology industries. Another element that is key to energy metabolism and bone and dental health [91] is phosphorus (P), which is found in fruit pomace. Calcium (Ca), in amounts of 200–500 $mg \cdot kg^{-1}$, plays a role in maintaining bone and tooth structure and in the functioning of muscles, the nervous system, and the immune system [92].

Table 5. Elemental compositions of the fruit pomace.

Sample	Macroelements [$g \cdot kg^{-1}_{d.w.}$]			Microelements [$mg \cdot kg^{-1}_{d.w.}$]		
	K	P	Ca	Fe	Zn	Mn
A	8.29 ± 0.12 ^{d}	1.00 ± 0.02 ^{e}	0.48 ± 0.02 ^{c}	18.24 ± 0.83 ^{b}	3.05 ± 0.19 ^{c}	-
C	8.41 ± 0.02 ^{d}	1.16 ± 0.02 ^{d}	2.11 ± 0.05 ^{b}	5.59 ± 0.66 ^{b}	5.59 ± 0.66 ^{d}	12.29 ± 0.23 ^{b}
G	17.46 ± 0.03 ^{a}	1.52 ± 0.02 ^{c}	1.68 ± 0.03 ^{d}	24.53 ± 0.14 ^{b}	6.88 ± 0.42 ^{d}	-
R	10.84 ± 0.47 ^{c}	2.72 ± 0.02 ^{a}	1.82 ± 0.03 ^{d}	51.56 ± 7.75 ^{a}	17.48 ± 0.45 ^{a}	67.32 ± 0.91 ^{a}
RC	14.56 ± 0.73 ^{b}	2.31 ± 0.10 ^{b}	2.80 ± 0.22 ^{a}	42.91 ± 2.18 ^{a}	13.39 ± 1.26 ^{b}	12.64 ± 0.66 ^{b}

A—apple pomace, C—chokeberry pomace, G—grape pomace, R—raspberry pomace, RC—redcurrant pomace. The presented numbers represent the arithmetic mean of the measurements (n = 3) ± SD; a different letter in the rows indicates that the presented values were significantly different (Tukey test).

Table 4 shows that the grape pomace and the redcurrant pomace had the highest ash content. Ash content represents the total mineral content in foods [93]. A detailed analysis of the elements confirms, above all, the high potassium and phosphorus content in these by-products. Based on research reported by Mohamed Ahmed et al. [94], mineral elements, such as potassium (K), phosphorus (P), iron (Fe), and zinc (Zn), were also identified as dominant in grape pomace from different grape varieties. Differences in the content of these minerals may be related to both the grape variety and the environmental conditions prevailing at the place of cultivation. The potassium content ranged from 11.84 $mg \cdot g^{-1}_{d.w.}$ (Ekşikara variety) to 27.18 $mg \cdot g^{-1}$ (Antepkarası variety), the phosphorus content ranged from 15.61 $mg \cdot g^{-1}$ (Marcaş) to 31.57 $mg \cdot g^{-1}$ (Antepkarası), the iron content in the tested grape pomace ranged from 21.54 $mg \cdot g^{-1}$ (Antepkarası) to 54.68 $mg \cdot g^{-1}$ (Çalkarası), and the zinc content ranged from 12.64 $mg \cdot g^{-1}$ (Alfonso) to 22.51 $mg \cdot g^{-1}$ (Marcaş).

Grape pomace is therefore characterised by a significant mineral content, which indicates its potential use in dietary supplements and cosmetic products [95–97]. It can also be a valuable source of minerals used to enrich food and feed [98].

In contrast, 22 chemical elements were identified in the freeze-dried waste extract obtained from the Redpoll variety of redcurrant (*Ribes rubrum* L.) using inductively coupled plasma optical emission spectrometry (ICP-OES), with the highest concentrations found for potassium (K: 25.37 $mg \cdot g^{-1}$), phosphorus (P: 9.482 $mg \cdot g^{-1}$), magnesium (Mg: 0.724 $mg \cdot g^{-1}$), and calcium (Ca: 0.637 $mg \cdot g^{-1}$) [99].

Research conducted by Pieszka et al. [87] also indicates that fruit pomace is a good source of minerals, with the following content: P—1.49 $g \cdot kg^{-1}$ in apple pomace and 2.39 $g \cdot kg^{-1}$ in chokeberry pomace, Ca—1.5 $g \cdot kg^{-1}$ in dried apple pomace and 2.75 $g \cdot kg^{-1}$ in dried chokeberry pomace, Mg—0.45 $g \cdot kg^{-1}$ in apple pomace and 0.88 $g \cdot kg^{-1}$ in chokeberry pomace, Na—0.018 $g \cdot kg^{-1}$ of apple pomace and 0.037 $g \cdot kg^{-1}$ of chokeberry pomace, and K—4.49 $g \cdot kg^{-1}$ of dried apple pomace and 2.78 $g \cdot kg^{-1}$ of chokeberry pomace. In addition, the pomace contained significant amounts of such microelements as Fe (91.8 $mg \cdot kg^{-1}$ apple pomace, 197 $mg \cdot kg^{-1}$ chokeberry pomace), Mn (8.75 $mg \cdot kg^{-1}$ apple pomace, 31.5 $mg \cdot kg^{-1}$ chokeberry pomace), Zn (6.9 $mg \cdot kg^{-1}$ of apple pomace, 15.7 $mg \cdot kg^{-1}$ of chokeberry pomace) and Cu (1.36 $mg \cdot kg^{-1}$ of dried apple pomace and 1.95 $mg \cdot kg^{-1}$ of chokeberry pomace). In our study, the chokeberry and redcurrant pomace proved to be the best sources of calcium. In turn, the highest levels of iron and zinc were found in the raspberry and redcurrant pomace. The raspberry pomace was the best source of manganese.

4. Conclusions

The findings of this study confirm that fruit pomace, particularly from redcurrants, chokeberries, raspberries, grapes, and apples, can be a valuable secondary raw material with high nutritional and functional potential. It contains significant amounts of dietary fibre, minerals (such as potassium, phosphorus, magnesium, and calcium), protein, and natural pigments, making it suitable for use in functional foods, dietary supplements, and cosmetics.

Redcurrant pomace, in particular, stands out due to its high protein and fibre content combined with low carbohydrate levels, which makes it especially beneficial for health-conscious and metabolically sensitive consumers.

Moreover, the fruit pomace powders exhibited favourable technological properties, including high water-binding and swelling capacities, supporting their application as natural thickeners, stabilisers, or texture-enhancing agents. Their intense natural colouring also offers potential for replacing synthetic dyes in food and cosmetic formulations.

Overall, fruit pomace shows promise as an ingredient for health-promoting and sustainable product development. Further research should focus on optimising processing

methods and maximising the recovery and application of bioactive compounds contained in these by-products.

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Abbreviations

The following abbreviations are used in this manuscript:

TTA	Total Titratable Acidity
TSS	Total Soluble Solid
WHC	Water Holding Capacity
SC	Swelling Capacity
OHC	Oil Holding Capacity
L^*	Lightness
a^*	Changes in the colour from green to red
b^*	Changes in the colour from blue to yellow
C^*	Chroma
A	Apple Pomace
C	Chokeberry Pomace
G	Grape Pomace
R	Raspberry Pomace
RC	Red Currant Pomace
SDF	Soluble Dietary Fibre
IDF	Insoluble Dietary Fibre
TDF	Total Dietary Fibre
d.w.	Dry weight

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