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The Influence of Fruit Pomaces on Nutritional, Pro-Health Value and Quality of Extruded Gluten-Free Snacks

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Featured Application: Obtained results give insight into health promoting properties of potential gluten free cornmeal-based snacks.

Abstract: The processing of fruit generates large amounts of different by-products, such as pomace. The extrusion process gives an opportunity for their utilization as a good source of pro-health components. Therefore, this research focused on the utilization of fruit pomaces (cherries, blackcurrants, and chokeberries) as a value-added component of extruded corn snacks. The effect of the level of pomace addition on the content of bioactive polyphenols and nutritional value in cornmeal-based extrudates, as well as antioxidant capacity, was investigated. Additionally, the influence of fruit pomace on the quality of extruded gluten-free snacks was also investigated. It was found that pomace can be a good pro-health addition to corn snacks due to the enrichment of bioactive compounds and dietary fiber in this product. Especially valuable proved to be chokeberry pomace added at a 20% level. Such additions to snacks caused an increase in the content of total phenolic compounds, phenolic acids, flavonoids, flavonols, anthocyanins, and antioxidant activity, respectively, by about 10 times, 2 times, 5 times, 2 times, 10 times, and 5 times, as compared to control snacks. It was observed that the addition of chokeberry pomace did not worsen the physical properties (WBC, hardness, and expansion ratio) of the resulting snacks, which affect the quality of the obtained product. Therefore, such snacks could be recommended for commercial production in order to increase the availability of gluten-free products for people with celiac disease.

Keywords: corn snacks; dietary fiber; extrusion; fruit pomace; nutritional compounds; organic waste utilization; phenolic compounds; quality features

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Citation: Gumul, D.; Berski, W.; Zięba, T. The Influence of Fruit Pomaces on Nutritional, Pro-Health Value and Quality of Extruded Gluten-Free Snacks. *Appl. Sci.* **2023**, *13*, 4818. https://doi.org/10.3390/app13084818

Academic Editors: Luca Mazzoni, Franco Capocasa and Maria Teresa Ariza Fernández

Received: 2 March 2023
Revised: 5 April 2023
Accepted: 7 April 2023
Published: 11 April 2023

1. Introduction

Food processing leads to inevitable losses. According to a report, "Food wastage footprint: Impacts on natural resources–Summary report" [1], fruit processing, packing, distribution, and consumption respectively generate a huge quantity of fruit waste, approximately 1.81, 6.53, and 32.0 million tones worldwide, and most of this is being disposed of either by composting or dumping in landfills, causing environmental pollution [2]. In fruit and vegetable processing, a significant problem is the management or disposal of waste products—the parts not used during technological processing. This is between 10 and 35% of the weight of the processed raw material and includes peel, seeds, and pomace. By-products of fruit processing are created during the production of juices, pulps, and jams. In the juice production process, the pomace mass depends on the pressing efficiency. During traditional pressing, the proportion of pomace is 20–25% of the initial raw material weight [3]. The application of enzyme preparations that liquefy the pulp and the leaching of the pomace with water allows for a reduction in the pomace share to about 12% of the initial fruit weight. Population growth and dietary changes contribute to greater consumption of fruit and vegetables, which in turn results in an increase in the amount of waste associated with their processing. In Europe, by-products from fruit processing account for 8% of all waste from the food sector. In developing countries, the situation is much worse because the by-products of fruit processing are treated as negligible and redundant compared to processed fruit [3]. Other studies indicate the generation of about 50% of by-products during fruit and vegetable processing in the forms of unripe or damaged fruits and vegetables, cores, peels, and pomaces [4,5].

Poland is an important producer of fruits and products of their processing, such as juices. Such production generates a large quantity of by-products, such as pomaces, that are usually utilized as feed or as raw materials for microbial growth [6,7]. But from a nutritional point of view, fruit pomaces can be treated as an abundant source of health-promoting components, primarily polyphenols and dietary fiber (DF) [8–12]. Although pomaces are not expected to be consumed alone, they can be used as a valuable ingredient to extend the health-promoting properties of food. Such an application will allow for the utilization of a by-product, and at the same time, a value-added product will be created. Extruded snacks seem to fit within this objective, and therefore the research has concentrated on the utilization of fruit pomaces as an additive for extruded snacks with an increased level of health-promoting components (polyphenols and fibers) [13,14].

Extrusion is a high-temperature, short-term physical treatment during which food polymers (usually a cheap one, such as starch or cornmeal) at a relatively low moisture level are subjected to significant structural changes by the combined action of high temperature, pressure, and shear forces. As a consequence, a new product with completely new properties and qualities is created [14], such as breakfast cereals, crisp bread, baby and infant foodstuffs, snack-type foods, meat analogs, textured proteins, noodles, and pasta that could be manufactured in this way [15,16]. However, starch- or cornmeal-based extrudates are characterized by low nutritional value and thus relatively weak health-supporting properties. Moreover, the extrusion process leads to the loss of polyphenols, i.e., components with broad pharmacological effects [17–21]. Therefore, it is suggested to supplement raw cereal material with natural or synthetic phenolic compounds or enrich it with vegetables, fruits, or other ingredients before extrusion [17,22–26]. It should also be taken into consideration that extrusion gives a great opportunity to utilize raw material products with no previously recognized greater economic importance, such as fruit pomace. Moreover, such an approach could be seen as an implementation of the zero-waste strategy [27].

An additional aspect of this research was to pay particular attention to gluten-free products, which are low in many nutrients (particularly protein, ash, and dietary fiber), and by using enriching additives (fruit pomace), we enrich them with health-promoting ingredients, especially polyphenols, which are extremely valuable in the context of the increase in the incidence of celiac disease worldwide [28–30]. In this work, cornmeal snacks enriched with fruit pomace were investigated, creating a new assortment of gluten-free products with improved pro-health and nutritional value. According to Hooper et al. [28], up to 87% of adult celiac disease patients suffer from vitamin (B6, B12, A, and D), mineral (Zn, Cu, and Fe), and dietary fiber (it protects against hypertension and cancer) deficiency. Such a deficiency results in an increased risk of cancer, osteoporosis, and infertility occurrences [31]. Therefore, it is crucial to enrich gluten-free products with components rich in dietary fiber, polyphenols, and minerals, and as a result, fruit pomace can be recognized.

Therefore, the aim of this research was to investigate the effect of the fruit pomaces (cherries, blackcurrants, and chokeberries) at different levels of addition on the content of bioactive compounds and dietary fiber in gluten-free extruded corn snacks. Moreover, the antioxidant activity of such products was evaluated. Moreover, the functional properties of this type of product were analyzed, i.e., color, density, expansion, water absorption, and hardness. Additionally, the nutritional composition of the final product was analyzed.

2. Materials and Methods

2.1. Materials

The study material consisted of fruit pomaces (chokeberry—PCHB; cherry—PCH; blackcurrant—PBC) provided in dried form from a local fruit processing plant (Hortino, Leżajsk, Poland) and cornmeal (Sante, Warsaw, Poland). The fruit pomaces were tested for their bioactive compound content, and the obtained data were collected in Tables 1 and 2. The main research material was extruded corn snacks with the addition of fruit pomace. The control extruded sample was made of pure cornmeal; in regular samples, cornmeal was partially substituted at 5, 10, and 20% levels by fruit pomaces. Snacks produced with the addition of pomaces were denoted as ECHB-05, ECHB-10, and ECHB-20 (chokeberry), ECH-05, ECH-10, and ECH-20 (cherry), and EBC-05, EBC-10, and EBC-20 (blackcurrant pomace) for 5, 10, and 20% replacement of cornmeal, respectively.

Extrusion was performed in a single-screw laboratory extruder 20DN (Brabender, Duisburg, Germany), applying the following parameters: screw speed—190 rpm, dye diameter—4 mm, compression ratio—1:3, and temperature profile—100–120–140 °C. The moisture level of all premixes was equilibrated at 14%.

2.2. Methods

Chemical Analysis

The following analyses of pro-health compounds, bioactive components, and chemical composition were performed on pomaces and resulting extrudates.

2.2.1. Chemical Composition

Protein content (Nx5.7) was determined by the Kjeldahl method (AOAC method No. 920.87) using the Kjeltec 2200 extraction unit (Foss, Hillerød, Denmark), fat content by the Soxhlet method (AOAC method No. 953.38) using the Soxtec Avanti 2055 (Foss, Denmark), and ash (AOAC method: 920.183) and total sugar content (and AOAC method No. 930.05) were determined according to AOAC [32].

2.2.2. Dietary Fiber Content

The dietary fiber (DF) content of non-starch polysaccharides, i.e., soluble (SDF) and insoluble (IDF) dietary fiber, was determined by the enzymatic-gravimetric method [33]. TDF was calculated as the sum of soluble and insoluble fractions. Ground samples were dispersed in water and treated with alpha-amylase, protease, and glucosidase to remove starch and protein. For TDF, enzyme digestate is treated with alcohol to precipitate soluble dietary fiber before filtering, and TDF residue is washed with alcohol and acetone, dried, and weighed. For IDF and SDF, enzyme digestate is filtered, and residue (IDF) is washed with warm water, dried, and weighed. For SDF, the combined filtrate and washes are precipitated with alcohol, filtered, dried, and weighed. TDF, IDF, and SDF residue values are corrected for protein, ash, and blank.

2.2.3. Antioxidants Content and Antioxidant Activity

- Extraction Procedure

Antioxidant content and antioxidant activity were determined in ethanol extracts. 0.6 g of sample was dissolved in 30 mL of 80% ethanol, shaken in the dark for 120 min (electric shaker: type WB22, Memmert, Schwabach, Germany), and separated for 15 min at 1050× *g* using a centrifuge (type MPW-350, MPW MED Instruments, Warsaw, Poland). The supernatant was decanted and stored at −20 °C for further analysis.

- Total Phenolic Content (TPC)

Total phenolic content (TPC) was determined by a spectrophotometric method using the Folin-Ciocalteu reagent, according to Singleton et al. [34]. The ether extract was 10 times diluted to a volume of 50 mL with distilled water in a volumetric flask. Five milliliters of extract was combined with 0.25 mL of Folin–Ciocalteau reagent and 0.5 mL of 7% Na_2CO_3.

The content was vortexed (WF2, Janke, and Kunkel, Staufen, Germany) and stored for 30 min in the dark. The absorbance was measured using Helios Gamma 100–240 (Runcorn, UK), at the wavelength λ = 760 nm. The results were expressed as mg catechin or gallic acid/100 g d.m.

2.2.4. Determination of Total Polyphenols

TPC, phenolic acids, flavonols, and anthocyanins were analyzed by a spectrophotometric method according to Mazza et al. [35] with modification by Oomah et al. [36]. Briefly, 0.1 mL of ethanol extract was taken into a test tube, and 2.4 mL of 2% HCl in 75% ethanol was added. The content of the tube was then mixed on a vortex (type WF2, Janke & Kunkel, Staufen, Germany), and the absorbance was measured in a spectrophotometer (Helios Gamma, 100–240, Runcorn, England) at λ = 280 nm (TPC), λ = 320 nm (phenolic acids), λ = 360 nm (flavonols), and λ = 520 nm (anthocyanins). A blank sample was prepared with 2% HCl in 75% ethanol and 80% ethanol. Results were expressed for TPC: mg catechin/100 g DM, phenolic acids: mg ferulic acid/100 g dm, flavonols: mg quercetin/100 g dm, and anthocyanins: mg glycoside-3-cyanidin/100 g dm.

2.2.5. Determination of Flavonoid Content

Determination of flavonoid content was performed using a method proposed by El Hariri et al. [37]. Specifically, 0.5 mL of ethanol extract was taken into a test tube, and 1.8 mL of distilled water and 0.2 mL of 2-aminoethyl diphenylborate reagent were added. The content of the tube was vortexed (Vortex type WF2, Janke & Kunkel, Staufen, Germany), and the absorbance was measured using a spectrophotometer (Helios Gamma, 100–240, Runcorn, England) at λ = 404 nm. At the same time, a blank test was performed by mixing 0.5 mL of 80% ethanol, 1.8 mL of distilled water, and 0.2 mL of 2-aminoethyl diphenylborate reagent. Flavonoid content was expressed as mg rutin/100 g d.m.

2.2.6. Antioxidant Activity (AA)

Antioxidant activity was assessed using analytical methods, namely ABTS [38]. ABTS was dissolved in the water to a 7 mM concentration. ABTS radical cation (ABTS+•) was produced by reacting ABTS stock solution with 2.45 mM potassium persulfate (final concentration) and allowing the mixture to stand in the dark at room temperature (12–16 h) before use. The bleaching rate of ABTS+• in the presence of the sample was monitored at 734 nm using a Helios Gamma 100–240 (Runcorn, UK) spectrophotometer. The ABTS+• solution was diluted in PBS buffer (pH 7.4) to give an absorption value of 0.700 ± 0.05 for the analysis of ethanol extracts. Volumes of 2.00 mL of ABTS+• and respective ethanol extracts in PBS buffer solution were used. The ABTS+• bleaching was monitored at 37 °C, and the discoloration after 6 min was used as the measure of antioxidant activity. Radical scavenging activity was measured as Trolox equivalent antioxidant capacity (mg Trolox per g of sample dm). Trolox solutions used for the calibration curve were in the concentration range 0–2.5 mM (R^2 = 0.9957). Additionally, AA was expressed as EC_{50} (mg/mL).

2.2.7. Physical Properties of Extruded Corn Snacks

Determination of the Density of Extrudates

The density of extrudates was determined using the displacement method [39] with rapeseed in two cylinders (1 mL graduation) and a RADWAG WPS 600/C balance (accuracy 0.001 g) (Radom, Poland). The commonly used relation mass/volume = density was applied.

Determination of Expansion Ratio of Extrudates

Ten pieces of extrudate were taken from the sample and separated for testing, and the diameter was measured in ten replicates using a caliper (accuracy 0.02 mm) [39]. The expansion ratio (er) was calculated as the ratio of the average diameter of the extrudates to the diameter of the extruder die nozzle using the following formula:

$$er = d/D \quad (1)$$

where:

d—extrudate diameter (mm)
D—extruder die nozzle (mm)

Water Binding Capacity (WBC) of Extrudates

One gram of whole extrudates was weighed, and distilled water at room temperature was added [37]. The whole was rehydrated for 1 h, after which time the extrudates were weighed and the amount of water bound by them was obtained from the difference in masses. The result was then converted to a ratio of 1 g of product. The determination was carried out in at least two replicates, and the result was taken as their average.

Extrudates Texture Profile Analysis (TPA) Using TA-XT Plus Texture Analyzer (Stable Micro Systems, Surrey, UK)

Texture analysis was carried out using a TA-XT Plus texture analyzer equipped with an HDP/KS5 Kramer Shear Cell 2 Blade (Stable Micro Systems Ltd. Manufactured in Surrey, UK). The device was calibrated prior to the test. A test was performed to cut through extrudates with a length of approximately 35 mm. A crushing speed of 2 mm/s and a distance of 20 mm were applied. The test was carried out with fifteen repetitions for each sample. By examining the crumb texture profile of the extrudates, its maximum cutting force was determined and expressed as hardness.

Instrumental Color Measurement in the CIE L* a* b* System

Instrumental measurement of the color components was performed with a Konica Minolta Inc. colorimeter, using the CIE L* a* b* system [38]. Before measuring the test samples, the instrument was calibrated on a white reference plate (L* = 98.45, a* = −0.10, and b* = −0.13). Measurements were carried out with the measuring head set at 8 mm, the observer at 2°, and illumination D65, which is daylight. The parameters analyzed were: brightness L* (L = 0 black, L = 100 white), red saturation a* (−a share of green, +a share of red), and yellow saturation b* (−b share of blue, +b share of yellow).

Furthermore, the total color difference (ΔE) and whiteness index (WI) were calculated [40]. ΔE was computed as the Euclidean distance between two points in the three-dimensional space defined by L*, a*, and b* using the following equation:

$$\Delta E = ((\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2)^{0.5} \quad (2)$$

where Δa*, Δb*, and ΔL* were the differences in the values of the respective parameters between the investigated samples.

The whiteness index (WI) indicates the whiteness degree, and was calculated as:

$$WI = 100 - ((100 - L)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{0.5} \quad (3)$$

Statistical Evaluation of Results

The results were statistically compared based on Duncan's test at a significance level of 0.05 using Statistica 8.0PL software. Moreover, the correlation coefficient was calculated. All measurements were performed at least in duplicate. The results were expressed as the mean ± standard deviation.

3. Results and Discussion

3.1. Characteristics of Fruit Pomaces

The content of bioactive compounds and chemical composition in fruit pomaces is summarized in Tables 1 and 2. The highest protein and fat content was found in blackcurrant pomace because it contained twice as much of these components as compared to chokeberry pomace. The highest amount of total carbohydrates was found in chokeberry pomace, 4 times and 3 times higher than in cherry and currant pomace, respectively. The chokeberry pomace contained the most minerals, 20% more than the other pomace. These results are in agreement with those of Kawecka and Galus [3] and Jurendic and Šcetar [41], who determined protein, fat, and ash in chokeberry pomace at levels of 4.9, 2.9, and 1.4–3.9 g/100 g dm, respectively. In the study of Alba et al. [42], the amount of protein, fat, and ash in currant pomace was 11.1–13.3, 5.9–10.9, and 2.8–3.8 g/100 g dm, respectively.

Table 1. Total phenolic, antioxidant activity, dietary fiber content, and chemical composition of fruit pomaces.

Pomace	Total Phenolic [1] mg Catechin/g dm	ABTS EC_{50} (mg/mL)	ABTS (TEAC) (mgTx/g dm)	Content of Dietary Fiber (g/100 g dm)		Chemical Composition (g/100 g dm)			
				Soluble Fraction	Insoluble Fraction	Protein	Total Sugar	Fat	Ash
PCHB	36.35 ± 0.30 c	0.47 ± 0.01 a	19.15 ± 0.09 c	5.71 ± 0.12 b	61.18 ± 0.00 b	6.80 ± 0.20 a	38.89 ± 0.30 c	4.70 ± 0.11 b	3.80 ± 0.00 c
PCH	18.87 ± 0.53 a	0.53 ± 0.00 c	18.15 ± 0.17 a	4.50 ± 0.23 a	44.20 ± 0.37 a	13.01 ± 0.12 b	10.71 ± 0.45 a	3.18 ± 0.14 a	2.8 ± 0.17 a
PBC	26.73 ± 0.71 b	0.51 ± 0.00 b	18.75 ± 0.23 b	5.36 ± 0.27 b	60.15 ± 1.11 b	17.50 ± 0.00 c	15.23 ± 0.17 b	10.10 ± 0.00 c	3.20 ± 0.08 b

The values in the column marked with the same letter are not significantly different at $p = 0.05$. [1] According to Singleton et al. [34].

Table 2. Selected phenolic compounds content in fruit pomace.

Pomace	Total Phenolic [1] mg Catechin/g dm	Phenolic Acid (mg Ferulic Acid/g dm)	Flavonoids (mg Rutin/g dm)	Flavonols (mg Quercetin/g dm)	Anthocyanins (mg Cyanidin-3-Glucoside/g dm)
PCHB	31.49 ± 0.23 c	2.163 ± 0.197 b	11.437 ± 0.053 c	1.714 ± 0.046 c	10.841 ± 0.332 c
PCH	5.89 ± 0.11 a	0.441 ± 0.020 a	2.289 ± 0.017 b	0.298 ± 0.00 a	0.475 ± 0.023 a
PBC	6.48 ± 0.34 b	0.460 ± 0.024 a	1.321 ± 0.032 a	0.429 ± 0.021 b	1.813 ± 0.162 b

The values in the column marked with the same letter are not significantly different at $p = 0.05$. [1] According to Mazza et al. [35], with modification by Oomah et al. [36].

It was found that the total polyphenol content was highest in PCHB and lowest in PCH. The content of this type of bioactive compound in PBC was lower by 26% as compared to PCHB and higher by 42% in relation to PCH (Table 1). This relationship was confirmed by Nawirska et al. [10]. It was found in their studies that PCHB was characterized by a high content of polyphenols, about 21% higher as compared to PBC. According to Sójka and Król [11], the amount of polyphenols ranged from 18.55–22.85 mg epicatechin/g in PBC, and in PCH, it was at 6.35 mg epicatechin/100 g [8]. According to Mayer-Miebach et al. [9], the amount of total polyphenols in PCHB ranged between 31 and 63 mg catechins/g. So, it could be stated that the total phenolic content identified in this study was consistent with the data provided by other authors.

The content of phenolic acids (PA) was the highest in PCHB, and the amount in PBC was four times lower, and in PCH it was five times lower as compared to PCHB. In the case of flavonoids, their highest content was recorded in the PCHB, analogous to the highest content of PA and total polyphenols in this kind of pomace. PCH and PBC were characterized by, respectively, 5 times and 8.5 times lower contents of flavonoids than PCHB (Table 2). A different trend was observed in the amounts of flavonols and anthocyanins in the studied fruit pomaces as compared to the content of flavonoids. Namely, the amount of flavonols and anthocyanins were in the following order: PCHB > PBC > PCH (Table 2). This difference between the content of flavonoids and the content of their fractions (flavonols and anthocyanins) could be due to other compounds such as isoflavones, chalcones, etc., which were not analyzed. In studies conducted by Vagiri and Jensen [12], the amount of anthocyanins in PCHB was 3.85 mg cyanidin-3-glucoside/g, and in the research of Mayer-Miebach et al. [9], it was 11.9–19.5 mg cyanidin-3-glucoside/g. The results of Jarosławska et al.'s [43] study on anthocyanin content in PBC were 0.4885 mg cyanidin-3-glucoside g. Some differences in the content of anthocyanins in the fruit pomace among the results of this work in comparison with results from other authors could be due to the different methods of extraction and anthocyanin assay.

AA determined by means of a synthetic free radical (ABTS) was in the following order: PCHB > PBC > PCH (Table 1), and it was positively correlated with the total phenol content in the pomace (r^2 = 0.985).

Another health-promoting compound, except for the previously mentioned polyphenols, present in fruit pomace was DF. The amount of this component in the PCHB and PBC was at the same level—approximately 60 g/100 g dm (IDF) and 5.5 g/100 g dm (SDF). Cherry pomace (PCH) was characterized by lower amounts of SDF and IDF, respectively 19% and 27%, in comparison with the remaining pomace (Table 1).

Among the analyzed fruit pomaces, PCHB was the most abundant in bioactive compounds. It contained the highest amounts of total polyphenols, PA, flavonoids, anthocyanins, and flavonols as compared to the remaining pomace. It was consistent with the results of the above-mentioned authors [9,10,12], and the content of DF in PCHB was identical to that in PBC (66 g/100 g dm). In contrast to the results obtained by Kawecka and Galus [3], in which the lowest amount of TDF was determined in chokeberry pomace, a higher one in blackcurrant pomace, and the highest in sour cherry pomace. This study also showed that TDF content in blackcurrant pomace was 59.7 g/100 g dm, and Alba et al. [42] showed a level of 72 g/100 g dm, and in the study by Jurendic and Šcetar [41], the TDF in chokeberry pomace was determined in the range of 63–78 g/100 g dm.

Fruit pomaces are a good source of bioactive compounds with health-promoting properties, and their application as an ingredient in snack production can improve the nutritional and pro-health values of the snacks.

3.2. Characteristics of Extruded Corn Snacks

3.2.1. Chemical Composition and Pro-Health Components in Extruded Corn Snacks with Fruit Pomace

As mentioned, cereal snacks are popular, and nutritionists are interested in their enrichment with all kinds of raw materials, including fruits, mixed fruits, and vegetables. Such snacks focus widespread attention among producers and food consumers. This is due to the fact that the search for a new product is still ongoing, and on the other hand, it relates to the growing consumer awareness of the relationship between the composition of the product and its nutritional and pro-health value. Such value in these snacks would consist of bioactive compounds, particularly polyphenols in the added fruit pomace.

Table 3 shows the chemical composition and contents of total polyphenols in corn extrudates with the addition of blackcurrant, cherry, and chokeberry pomace. It was found that after the application of fruit pomace, the protein content in the snacks decreased from 9% to 21% as compared to the control. This tendency can probably be explained by the fact that the amount of protein in cornmeal/corn grits (8.3%; Sante.pl, 2018) was 1.5 times higher than in chokeberry pomace (6.8/100 g dm). Therefore, the substitution of corn grits with these pomaces reduced the amount of protein in the final product. Definitely less protein reduction occurred in snacks with the participation of cherry and blackcurrant pomace because they contained much more of this compound. However, the amount of protein in extruded snacks decreased with the application of fruit pomace because the extrusion process itself can lead to a reduction in the protein content [15], as protein losses are mainly associated with the combination of simple sugars with amino acids during thermally induced Maillard reactions. Moreover, during the extrusion process, proteins are bound to fats, which can result in some losses of this nutrient [44,45].

Table 3. Chemical composition and total phenolic content, antioxidant activity, and dietary fiber content of corn extrudates with fruit pomace.

Sample	Total Phenolic [1] mg Catechin/g dm	ABTS EC_{50} (mg/mL)	ABTS (TEAC) (mgTx/g dm)	Content of Dietary Fiber (g/100 g dm)		Chemical Composition (g/100 g dm)			
				Soluble Fraction	Insoluble Fraction	Protein	Total Sugar	Fat	Ash
Control	1.19 ± 0.37 [a]	2.34 ± 0.11 [f]	3.74 ± 0.11 [a]	0.12 ± 0.00 [a]	0.83 ± 0.01 [a]	7.32 ± 0.03 [c]	2.32 ± 0.12 [a]	1.88 ± 0.17 [b]	1.19 ± 0.00 [a]
ECHB-05	3.76 ± 0.00 [c]	1.00 ± 0.07 [cd]	9.74 ± 0.23 [f]	0.92 ± 0.11 [b]	2.95 ± 0.05 [b]	6.07 ± 0.15 [a]	3.52 ± 0.07 [c]	1.72 ± 0.08 [b]	1.33 ± 0.12 [ab]
ECHB-10	4.23 ± 0.13 [d]	0.76 ± 0.01 [c]	13.14 ± 0.10 [h]	1.07 ± 0.07 [b]	6.03 ± 0.07 [e]	5.93 ± 0.70 [a]	4.00 ± 0.14 [d]	1.70 ± 0.03 [b]	1.48 ± 0.03 [b]
ECHB-20	13.44 ± 0.43 [g]	0.52 ± 0.03 [a]	18.14 ± 0.09 [i]	1,96 ± 0.17 [c]	8.83 ± 0.00 [h]	5.75 ± 0.23 [a]	4.37 ± 0.00 [e]	1.68 ± 0.12 [a]	1.63 ± 0.07 [c]
ECH-05	2.10 ± 0.07 [b]	1.45 ± 0.17 [e]	4.74 ± 0.34 [b]	0.78 ± 0.11 [b]	2.75 ± 0.17 [b]	6.42 ± 0.17 [a]	2.87 ± 0.09 [b]	1.58 ± 0.13 [a]	1.20 ± 0.00 [a]
ECH-10	3.48 ± 0.28 [c]	1.21 ± 0.00 [e]	7.14 ± 0.25 [d]	0.98 ± 0.05 [b]	5.07 ± 0.23 [d]	6.01 ± 0.00 [a]	3.12 ± 0.10 [bc]	1.71 ± 0.00 [b]	1.28 ± 0.02 [ab]
ECH-20	4.97 ± 0.02 [e]	0.86 ± 0.10 [c]	11.74 ± 0.56 [g]	1.22 ± 0.15 [b]	6.90 ± 0.41 [f]	5.94 ± 0.12 [a]	4,01 ± 0.12 [d]	1.70 ± 0.14 [b]	1.32 ± 0.11 [ab]
EBC-05	2.35 ± 0.17 [b]	1.26 ± 0.07 [e]	5.74 ± 0.24 [c]	0.93 ± 0.23 [b]	3.60 ± 0.00 [c]	6.68 ± 0.10 [b]	3.13 ± 0.14 [bc]	1.90 ± 0.32 [b]	1.23 ± 0.08 [a]
EBC-10	3.38 ± 0.08 [c]	1.17 ± 0.10 [e]	7.94 ± 0.17 [e]	1.03 ± 0.12 [b]	6.28 ± 0.12 [e]	6.47 ± 0.08 [ab]	3.87 ± 0.11 [d]	2.01 ± 0.15 [b]	1.30 ± 0.00 [ab]
EBC-20	5.93 ± 0.03 [f]	0.62 ± 0.00 [b]	17.76 ± 0.47 [i]	1.79 ± 0 [c]	8.53 ± 0.00 [g]	6.07 ± 0.00 [a]	4.12 ± 0.07 [d]	2.37 ± 0.03 [c]	1.42 ± 0.11 [ab]

The values in the column marked with the same letter are not significantly different at $p = 0.05$. [1] According to Singleton et al. [34].

The fat contents in the extrudates with fruit pomace and the control sample were at similar levels, and the highest fat content was a result of the largest addition (20%) of currant pomace (Table 3). A slight reduction in the fat content or its stabilization in the mixture after extrusion can most likely be the result of combining fat with starch or proteins [45,46].

The content of total sugars in the extrudates depended on the share and type of the applied pomace and increased from 24 to 88% in relation to the control (Table 3). This was due to the addition of a fruit component rich in sugar, which is fruit pomace, as well as the degradation of starch chains during the extrusion process [46]. Results similar to those observed in this work were also reported by Gumul et al. [47], where, with the increasing share of defatted blackcurrant seeds from 10% to 50%, the content of total sugars in the extrudates also increased (from 12% to 415%) at 50% addition of blackcurrant seeds).

The ash content in the samples with fruit pomace addition was constant or slightly increased as compared to the control. Changes in the ash content in final products were mainly related to the applied raw materials, i.e., the increasing share of fruit pomace, because, as reported by Henry and Chapman [46], the amount of minerals in the plant material does not increase after extrusion.

It was found that each of the analyzed fruit pomaces increased the content of bioactive compounds in extrudates. For PBC addition to corn snacks, the increase in polyphenol content ranged from 97% to 398%, based on the control sample. PCH contributed to the increase in polyphenols in the range of 76% to 318% in extruded corn snacks as compared to the control. Moreover, extrudates enriched with chokeberry pomace were characterized by a higher content of these ingredients in the range of 216% to 1030% compared to pure corn extrudates (Table 3). A general observation was made: the increase in the content of polyphenols was a function of the amount of pomace introduced into extrudates. PCHB had the greatest impact on polyphenol content because, in snacks with such an addition, it recorded the highest content of the previously mentioned bioactive compounds (Table 3). Total phenolic content was measured by two methods because the Folin–Ciocalteu reagent [34] can react with other compounds such as vitamin C, some alkaloids, amino acids, and proteins. Therefore, another method by Mazza et al. [35] with modification by Oomah et al. [36] was also applied, and the results were collected in Table 4. It was found that PCHB, PCH, and PBC increased the total phenolic content in corn extrudates as measured without applying the Folin–Ciocalteu reagent, respectively, by about 450%, 240%, and 256%, as compared to a reference sample. It was also noted that the increase in total phenolic content in the extrudates was adequate for the amount of supplement added, and the highest content of these bioactive components was determined in ECHB-20, which was similar to the total phenolic content marked with the Folin–Ciocalteu reagent (Tables 3 and 4). It was observed that the introduction of fruit pomace into corn extrudates increased the amount of PA content by about 70% in the case of PCHB addition, 24% for PCH, and 31% for PBC as compared to the control. It was also noted that regardless of the type of pomace, their 5% and 10% additions resulted in an identical increase in phenolic acid content in extrudates, and only 20% supplementation contributed to a significant increase in the low molecular weight bioactive compound content (PA) in the investigated extrudates (Table 4).

Table 4. Selected phenolic compounds and flavonoids content in corn extrudates with addition of fruit pomace.

Sample	Total Phenolic [1] mg Catechin/g dm	Phenolic Acid (mg Ferulic Acid/g dm)	Flavonoids (mg Rutin/g dm)	Flavonols (mg Quercetin/g dm)	Anthocyanins (mg Cyanidin-3-Glucoside/g dm)
Control	0.893 ± 0.032 [a]	0.255 ± 0.000 [a]	0.266 ± 0.021 [a]	0.200 ± 0 [a]	0.068 ± 0.011 [a]
ECHB-05	3.550 ± 0.119 [d]	0.324 ± 0.006 [bc]	0.528 ± 0.014 [e]	0.230 ± 0.002 [b]	0.407 ± 0.00 [d]
ECHB-10	4.197 ± 0.076 [e]	0.379 ± 0.006 [c]	0.891 ± 0.009 [f]	0.258 ± 0.003 [c]	0.457 ± 0.017 [e]
ECHB-20	6.987 ± 0.374 [g]	0.590 ± 0.032 [d]	1.75 ± 0.057 [g]	0.389 ± 0.022 [d]	0.761 ± 0.034 [f]
ECH-05	1.860 ± 0.114 [b]	0.291 ± 0.009 [b]	0.328 ± 0.017 [b]	0.208 ± 0.006 [b]	0.321 ± 0.012 [b]
ECH-10	3.067 ± 0.139 [c]	0.295 ± 0.012 [b]	0.384 ± 0.004 [c]	0.216 ± 0.008 [b]	0.337 ± 0.00 [b]
ECH-20	4.138 ± 0.145 [e]	0.365 ± 0.015 [c]	0.511 ± 0 [e]	0.248 ± 0.008 [bc]	0.368 ± 0.013 [c]
EBC-05	2.002 ± 0.114 [b]	0.298 ± 0.014 [b]	0.447 ± 0.028 [d]	0.231 ± 0.009 [b]	0.364 ± 0.007 [c]
EBC-10	3.061 ± 0.410 [cd]	0.327 ± 0.026 [bc]	0.503 ± 0.017 [e]	0.261 ± 0.017 [c]	0.380 ± 0.008 [c]
EBC-20	4.500 ± 0.062 [f]	0.375 ± 0.017 [c]	0.907 ± 0.042 [f]	0.287 ± 0.009 [c]	0.430 ± 0.012 [e]

The values in the column marked with the same letter are not significantly different at $p = 0.05$. [1] According to Mazza et al. [35], with modification by Oomah et al. [36].

Taking into account high molecular weight phenolic compounds, i.e., flavonoids, it was found that the lowest content of these compounds was found in the control sample. However, whatever type of fruit pomace was introduced, an increase in the content of high molecular weight phenolic compounds in snacks was observed in the range of 23% to 557%, as compared to the control (Table 4). The highest increase in the amounts of these bioactive compounds reported for PCHB addition is about 98% to 557%. The highest content of flavonoids among all analyzed corn snacks was observed in the extrudate with a 20% addition of PCHB (Table 4).

Moreover, a gradual increase in the amount of high molecular weight polyphenols (flavonoids) was also observed in the analyzed samples, appropriate to an increase in the amount of additive (Table 4). In contrast, an increase in the flavonol content was not adequate for the amount of additive introduced into corn extrudates. Additionally, it was observed that a 5% addition of pomace caused the same increase in flavonols (about 13%), regardless of their type. Only higher levels of these additives guarantee a greater increase in the flavonol content of extruded corn snacks compared to the control. The biggest increase in the flavonol content was recorded in the case of PCHB-supplemented snacks—about 61%—and the lowest was 16% for PCH (Table 4). In the case of the second fraction of flavonoids, i.e., anthocyanins, it was observed that for 5% and 10% PCH and PBC added, the increase in the content of these compounds was, respectively, 3.8-fold and 4.3-fold in extrudates as compared to control. A twenty percent addition of the above-mentioned pomaces caused the greatest increase in the amount of anthocyanins: 4.4-fold for PCH and 5.3-fold for PBC (Table 4). The anthocyanin content increased progressively with the amount of the applied additive in the form of PCHB. While the content of anthocyanins in extrudates with PCHB was low, only this pomace among all those analyzed guaranteed a 5- to 10-fold increase in anthocyanin content in extrudates. Generally, low levels of anthocyanins in the corn extrudates increase with the addition of fruit pomace, resulting from their high thermolability. The anthocyanins' stability during the extrusion depends on their type. In blackcurrants, cherries, chokeberries, blueberries, and cranberries, non-acylated anthocyanins are present, which are less stable and bioavailable than the acylated anthocyanins present in red potatoes [48,49]. Hence their low amount in the extruded snacks (Table 4). Despite this, PCHB ensured an increase of 5 to 10 times in the anthocyanin content of snacks. In the context of the health-promoting properties of anthocyanins, namely their anti-mutagenic, anticarcinogenic, and antihypertensive activity, and reduced risk of chronic diseases and neuronal degeneration [50–52], this seems to be an important achievement of this work. Especially anthocyanins from chokeberries show inhibition of cancer cell proliferation and antimutagenic, hepatoprotective, antidiabetic, and cardioprotective effects [53], which additionally supports the fact that health-promoting extruded corn snacks supplemented with chokeberry pomace can be produced.

Taking into consideration the fact that extrusion could cause a reduction in the polyphenol content in the range of 24% to 46% [17], it should be noted that the additive-enriched corn snacks applied in this work are high in polyphenolic compounds, despite the loss of these components resulting from the partial depolymerization, decarboxylation (in the case of phenolic acids), and the polymerization of phenolic compounds and tannins [18] during extrusion. Among all analyzed fruit pomaces, the largest increase in polyphenols, phenolic acids, flavonols, and anthocyanins in extruded corn snacks guarantees PCHB (Table 4).

The results of the AA analysis of the samples determined by the method with a synthetic free radical ABTS are summarized in Table 3. It was found that each of the additives contributed to an increase in this type of activity of the extrudates, on average by 265% for PCHB added, about 108% for PCH, and 180% in the case of PBC (Table 3). AA of the analyzed snacks incorporating fruit pomace was adequate for the content of total polyphenols, as was evidenced by the strong positive correlation between the total phenolic content and ABTS (r^2 = 0.829). Exceptions were observed for ECHB-20 and EPBC20, which have identical AA despite significant differences in the total polyphenol content. Most likely, this must be attributed to the fact that other compounds, not analyzed in this research (such as tannins as well as new compounds formed by extrusion, such as Maillard reaction products or the conversion of less active antioxidants into more active antioxidants [54]), contributed to AA.

AA was also calculated as EC_{50}, i.e., the concentration of antioxidants necessary to neutralize 50% of the ABTS present in the sample; the lower the EC_{50} value, the higher the antioxidant activity of the polyphenols in the sample. When AA was calculated as Trolox (TEAC) and EC_{50}, an inverse relationship was clear. Among the analyzed samples, snacks with a 20% share of PCHB had the highest AA because their EC50 was the lowest.

In studies conducted by Ainsworth et al. [55], the brewer's spent grain was applied, but with no effect on the content of polyphenols or the antioxidant activity of the investigated samples. Moreover, adding the cauliflower by-product to extrudates did not increase the polyphenol level, but it had a detrimental effect on the antioxidant activity [23]. Similarly, the addition of brewer's spent grain to cereal extrudates resulted in no observed changes in polyphenol levels or antioxidant activity [56]. In Camire et al.'s [22] study on the effect of blueberry, cranberry, concord grape, and raspberry additions on the amount of polyphenols in extrudates, there were no changes in the amount of these compounds, most likely as a result of a too low share—only 1%. However, the addition of red cabbage to cereal snacks resulted in a marked increase in the polyphenol content and antioxidant activity [56]. Other research [57] dealing with cereal snacks supplemented with defatted blackcurrant seed noted a 2- to 10-fold increase in the levels of polyphenols and a 2- to 11-fold increase in antioxidative activity as compared to the control. Moussa-Ayoub et al.'s [58] investigation on the enrichment of cereal-based extrudates with cactus fruits led to an increase in the antioxidative activity of the final product, adequate to the amount of the applied supplement. Similarly, Anton et al. [59] observed a significant increase in total polyphenols by about 40% and the antioxidant activity of 98% of the extruded snack obtained from blends of corn starch and navy red beans. Taking into account the results of the presented research, it can therefore be said that the applied fruit pomace can be a perfect health-promoting addition to corn extrudates because it will enrich the final product with a wide range of bioactive compounds from the polyphenols group, ranging from low molecular phenolic acids to anthocyanins (Table 4). Of particular value proved to be PCHB, as ECHB-20 was characterized by the highest content of polyphenols, phenolic acids, flavonols, flavonoids, and anthocyanins (Table 4).

Another very important pro-health component present in the fruit pomace was DF. IDF content was 67 g/100 g dm and 65 g/100 g dm, respectively, for PBC and PCH pomace, and 48.7 g/100 g dm in PCH. The above-mentioned pomaces were used to enrich the resulting extrudates with DF (Table 3). PCHB contributed to the largest, 10-fold increases in the amount of SDF and 6-fold increases in the amount of IDF in extrudates, and PCH addition resulted in the smallest increase, approximately 7-fold and 5.5-fold, respectively (Table 3). Taking into account the fact that SDF has hypocholesterolemic and hypoglycemic properties [60] and IDF has anticancerogenic characteristics [61], the introduction of fruit pomace, which caused such a high increase in DF content in snacks, appeared to be justified. It should also be stressed that not every supplement helped to increase the amount of DF; for example, the addition of extrudates of cauliflower by-product (5–20%) contributed to the decrease in fiber content, which was the result of pectin degradation into low molecular weight compounds, which were not assayed by the applied analytical method [23]. Results from Gumul et al. [57] indicated that defatted blackcurrant seeds contributed to a 2.5-fold increase in SDF and an 8-fold increase in IDF in corn extrudates. Potter et al. [62] reported that the addition of fruit mixtures to extrudates resulted in an increase in the soluble dietary fiber fraction in the range of 50–350% and that the content of IDF was not changed compared to the control.

3.2.2. Quality of Extruded Corn Snacks with Fruit Pomace

Some of the most important parameters for the qualitative evaluation of extruded snack products are density and expansion, especially in terms of assessing their textural properties [63].

Expansion and density of extrudates are quantities that are most often inversely proportional; that is, as the expansion factor increases, the density decreases [47,62]. Both quantities are largely dependent on the dietary fiber (DF) content, especially its soluble and insoluble fractions (SDF and IDF).

It was observed that adding chokeberry, cherry, and blackcurrant pomace increased the extrudates' density, with the higher the level of additive used, the higher the density relative to the control. With a 20% level of the various additives, the density of the extruded snacks was almost 1.5 to 2 times higher as compared to the control. In contrast to the 5% additive, which did not affect this parameter regardless of the type of additive used (pomace-cherry, chokeberry, or blackcurrant) (Table 5).

Table 5. Physical properties of extrudates of corn extrudates with addition of fruit pomace.

Sample	Density [g/cm^3]	Expansion Ratio [%]	WBC [1] [%]
Control	0.064 ± 0.01 ^{a}	4.24 ± 0.76 ^{a}	4.38 ± 0.12 ^{e}
ECHB-05	0.072 ± 0.01 ^{a}	4.58 ± 0.25 ^{a}	3.21 ± 0.09 ^{c}
ECHB-10	0.118 ± 0.01 ^{c}	4.23 ± 0.13 ^{a}	2.84 ± 0.00 ^{b}
ECHB-20	0.138 ± 0.00 ^{d}	4.18 ± 0.15 ^{a}	2.34 ± 0.07 ^{a}
ECH-05	0.059 ± 0.02 ^{a}	4.11 ± 0.18 ^{a}	3.58 ± 0.00 ^{d}
ECH-10	0.084 ± 0.00 ^{ab}	4.29 ± 0.30 ^{a}	2.99 ± 0.17 ^{b}
ECH-20	0.110 ± 0.02 ^{c}	4.12 ± 0.09 ^{a}	2.57 ± 0.21 ^{a}
EBC-05	0.073 ± 0.02 ^{a}	3.89 ± 0.11 ^{a}	3.37 ± 0.00 ^{c}
EBC-10	0.087 ± 0.02 ^{ab}	4.05 ± 0.25 ^{a}	2.87 ± 0.03 ^{b}
EBC-20	0.127 ± 0.02 ^{d}	4.03 ± 0.23 ^{a}	2.42 ± 0.05 ^{a}

The values in the column marked with the same letter are not significantly different at $p = 0.05$. [1] WBC—water binding capacity.

It was found that the expansion of extruded snacks with fruit pomace did not change in relation to the control, regardless of the proportion of such an additive (Table 5).

The expansion of the extruded snacks is mainly ensured by the starch present in the mixture, which is characterized by viscoelastic properties. Bubbles formed by the evaporation of the water present in the extruded material penetrate into the swelling starch granules and cause them to expand [24]. As a result of replacing cornmeal, which is a source of starch, with fruit pomace, which in turn is a source of dietary fiber, there is, among other things, a reduction in the extensibility of the bubbles formed, which has the effect of reducing the expansion ratio and increasing the density of the obtained extruded products [64].

In addition to the above-described reduction in gas bubbles, the IDF fraction also causes their damage, acting as a disintegrating agent [25]. In addition, the SDF fraction (mainly pectin) present in the pomace, which is characterized by a high water-absorbing capacity, contributes to starch water-absorption reduction, thus inhibiting the expansion process of the product [25]. Although, on the other hand, according to van der Sman and Broeze [64], this fraction can at the same time favor the product expansion process—by increasing the elasticity of the forming "sources" of gas bubbles.

Furthermore, the extrusion process will not only result in pasting but also in the melting of the starch polymer, which, according to Colonna and Mercier [65], partially adheres to the cellulose walls, causing the formation of structural complexes containing cellulose, partially melted starch, and proteins, thus limiting the product's ability to expand and therefore increasing its density [65,66]. An additional component limiting the expansion of these extrudates is the water-soluble saccharides in the extrudate. These saccharides limit the amount of water available for bubble formation and starch pasting, which reduces the extent to which these processes occur and leads to a lower expansion factor [47,67].

In the subject of research on the influence of carbohydrate raw materials used as additives to extruded products on expansion and density, wheat, oat, or rye brans were commonly applied additives. Their addition resulted in an increase in IDF fraction content, a simultaneous increase in the density of the extrudates obtained, and a decrease in the expansion factor. This was due to the high fiber content of the additives used as well as the high fat content of oat bran, whose content also affected expansion [68,69].

The addition of buckwheat flour to corn extrudates showed that the density increased with an increased proportion of this ingredient, while only a 50% addition of buckwheat or higher increased the expansion factor. This was related to the components that buckwheat provides, including protein and dietary fiber [70]. It has been demonstrated that enrichment with dried potato juice and various vegetable additives such as paprika, basil, or parsley causes an increase in the density of extrudates with an increased proportion of the applied additive and a decrease in the coefficient of expansion, with an increase in the content of the additive particularly rich in DF [71].

Among the fruits, the effect of elderberries on the density of the extrudates was investigated; the value increased, but the addition of elderberries could not exceed 15% because this would cause unfavorable quality characteristics in the final product. The addition of apple pomace was also applied, which resulted in an increase in density and a decrease in the expansion factor compared to the control sample, despite a slight increase in the SDF fraction [72].

In the case of the water binding capacity (WBC) of the extruded corn snacks obtained with the addition of fruit pomace, a decrease in this parameter's value was observed with an increase in their proportion compared to the control sample (Table 5). In the case of chokeberry pomace, the decrease in WBC of the extrudates with its share ranged from 27–47% as compared to the control (Table 5). In the case of cherry and currant extrudates, the decrease in WBC of extrudates containing them ranged from 18–41% and 25–45%, respectively, relative to the control (Table 5).

Ačkar et al. [72] also observed a decrease in WBC for corn extrudates with different proportions of apple pomace (from 6% to 23%) as compared to control corn extrudate. Slightly different results were obtained by Gumul et al. [47], where extrudates with 10% and 30% blackcurrant seeds had a higher WBC than the control sample, while a 50% share of blackcurrant seeds resulted in a 46% decrease in WBC. This was probably related to the low starch content and high sugar content of the finished product with 50% blackcurrant seeds (322% less starch and 415% more saccharides in the sample with 50% as compared to the control). Contrary, Drożdż et al. [73] investigated the WBC of corn extrudates with the addition of blackcurrant and chokeberry press pulp and found an unambiguous decrease in WBC as the proportion of both fruits in the extrudates increased. According to Drożdż et al. [73], this can be due to the high fiber content. The results ranged from 6.4–4.6% for extrudates with blackcurrant and 5.9–4.8% for extrudates with chokeberry, while for the control sample, it was 6.5% [73]. The observed decrease in WBC of the corn extrudates analyzed in this study with different proportions of fruit pomace was most likely related to the high content of sugars in them, which significantly reduces the amount of water available for the starch pasting process. This effect can also be attributed to the decreasing starch content (replacing cornmeal as a source of starch with extrudate as a source of fiber) with an increasing proportion of fruit pomace in the extrudate, which contains a huge proportion of fiber. This resulted in competition for water between the fiber present in the fruit pulp and the available starch [74].

In addition, it should be mentioned that during the extrusion process, starch undergoes not only pasting but also thermal and mechanical degradation and complex formation with proteins and fats, as well as dilution in the extrusion mixture, which reduces its water-absorbing capacity [45]. The decrease in WBC of the resulting extrudates may also be partly related to the reduction during extrusion of the hydrophilic protein content due to its thermal denaturation as well as its complexation with starch [75].

Based on an analysis of the color parameters (L* a* b*), it was observed that the color of the extrudates was significantly affected by the applied additive. The addition of chokeberry pomace resulted in a significantly darker color of the finished product as compared to the sample without any additive, with a decrease in brightness and yellow saturation but an increase in red saturation (Table 6). On the other hand, the addition of cherry pomace also caused a decrease in lightness and yellow saturation and an increase in red saturation, but not as much as the addition of chokeberries. These changes were more noticeable with the addition of chokeberry pomace than with cherry pomace (Table 6). In contrast, blackcurrant pomace contributed to intermediate changes in the color parameters of the extruded snacks compared to the other pomace. Many authors who carried out studies on the effect of the additive used on the color parameters of extruded snacks also showed significant discrepancies in the level of brightness or color saturation, this being mainly dependent on the amount and type of additive used. Kowalczewski et al. [71] investigated how dried potato juice and various vegetable additives would affect individual color components. They used paprika, parsley, and basil as additives. All these additives decreased lightness with the increased addition of the enhancement component. The addition of paprika resulted in a significant increase in red color saturation, and in the case of parsley and basil, in green color saturation. Among fruits, the effects of elderberry and chokeberry [76] on individual color components were investigated. These additives caused a decrease in lightness and yellow saturation and a significant increase in red saturation. Drożdż et al. [77] studied the color of corn extrudates with the addition of pomace from apples (10, 15, and 20%) and rosehips (10, 15, and 20%) as compared to the control sample. The increase in pomace content resulted in a decrease in the parameter L*—the lightness of the investigated extrudates changed from 56.54 to 52.09. These results were much lower than the lightness of the control sample, whose brightness was 64.43 [77]. For the parameter a*, the addition of both types of pomaces resulted in a higher proportion of red color in the extrudates compared to the control sample, whose value was on the negative side (−4.21). Extrudates with a 20% addition of rosehip pomace contained the reddest color, while extrudates with a 10% addition of apple pomace contained the least [77].

Table 6. Color parameters of corn extrudates with addition of fruit pomace.

Sample	L* [-] (Black to White)	a* [-] (Green to Red)	B [-] (Blue to Yellow)	WI [-]	ΔE [-]
Control	78.01 ± 0.12 g	0.78 ± 0.27 a	17.46 ± 0.18 h	71.91	-
ECHB-05	53.43 ± 1.54 d	9.11 ± 0.30 f	10.25 ± 0.28 d	51.45	26.94
ECHB-10	48.31 ± 0.47 c	9.48 ± 0.13 g	9.00 ± 0.15 c	46.68	32.08
ECHB-20	30.20 ± 0.19 a	10.57 ± 0.51 g	7.12 ± 0.11 a	29.05	49.89
ECH-05	66.16 ± 0.16 f	5.19 ± 0.07 b	14.46 ± 0.14 g	62.84	13.00
ECH-10	60.62 ± 0.22 e	6.64 ± 0.06 b	13.7 ± 0.18 e	57.78	18.73
ECH-20	50.31 ± 1.21 d	7.12 ± 0.08 d	12.10 ± 0.1 e	48.36	28.92
EBC-05	60.73 ± 0.11 e	7.39 ± 0.00 d	9.90 ± 0.03 d	58.83	19.99
EBC-10	53.20 ± 0.76 d	8.52 ± 0.05 e	8.57 ± 0.12 c	51.66	27.47
EBC-20	45.20 ± 0.19 b	9.57 ± 0.09 g	7.32 ± 0.00 b	43.89	35.45

The values in the column marked with the same letter are not significantly different at $p = 0.05$. L*, a*, b*—parameters of color in lab color space; WI—whiteness index; ΔE—color difference between control sample and other samples.

On the other hand, when the parameter b* was investigated, it was noted that samples with pomace showed lower values compared to extrudates made from cornmeal only, which had a value of 38.39. The highest value of the b*parameter was measured in extrudates with a 20% addition of rosehip (27.99) and the lowest in extrudates with a 20% apple pomace addition [77].

The introduction of fruit pomaces into snacks resulted in a decrease in WI values, indicating a shift from white color (Table 6), which was increasing with the share of added pomaces. The greatest decrease was observed for extrudates prepared with the addition of chokeberry (ECHB) and the smallest for those with cherry pomace (ECH) addition.

Moreover, the color difference (ΔE) between the control and other investigated samples was evaluated. Similarly, for WI, the same trend was observed—an increasing share of pomace resulted in increased ΔE values. In addition, the greatest differences between control and experimental samples were observed for ECHB samples, whereas the smallest were observed for ECH.

It can be assumed that a ΔE value up to 2.3 corresponds to a just noticeable difference (JND) in color between the two samples [78,79]. Such a low difference was only observed between EBC-10 and ECHB-05 (1.8) (Table S1). According to the aforementioned authors for ΔE values < 3:5, an inexperienced observer also noticed the difference, and such a situation occurred between the ECHB-10 and EBC-20 samples.

Data related to the hardness measurement of selected corn extrudates are summarized in Table 7. The addition of fruit pomaces resulted in decreased hardness (cutting force) as compared to the control sample. Such behavior could be explained by the partial replacement of starch polymers, which were subjected to melting during the extrusion process, forming a matrix for other ingredients in the extruded snack. Such replacement resulted in a more brittle structure, and less effort was required to cut the extrudate.

Table 7. Hardness of selected corn extrudates with addition of fruit pomace.

Sample	Hardness [N]
Control	36.37 ± 8.86 c
ECHB-05	24.63 ± 4.8 b
ECHB-10	14.32 ± 6.17 a
ECH-05	29.24 ± 6.49 b
ECH-10	30.58 ± 6.75 bc

The values in the column marked with the same letter are not significantly different at $p = 0.05$.

In a study by Gumul et al. [57], a decrease in corn snack hardness was also observed when defatted blackcurrant seeds were added (an average decrease of 53% compared to the control). In contrast, in the study by Stojceska et al. [23], where different proportions of ground dried cauliflower were used to produce corn-wheat extrudates, no increase in hardness was found with increasing proportion of the additive, despite the fact that such an increase was expected based on the study of Yannioti et al. [80], who, as mentioned earlier, proved that the DF addition increases the hardness of the obtained extrudates. It should also be kept in mind, as mentioned in the case of gluten-free extrudates, the partial effect of pectin, which is part of the SDF fraction of the pomace, can reduce the hardness of the obtained expanded products [80].

4. Conclusions

It was found that the applied fruit pomace can be a great addition to pro-health corn extrudates because it enriched the final product with bioactive components from the polyphenols group, as well as nutritional compounds (ash and sugar) and dietary fiber. Particularly valuable proved to be chokeberry pomace, and as an extruded corn snack with a 20% addition of such pomace, they were characterized by the highest content of polyphenols, phenolic acids, flavonoids, flavonols, anthocyanins, SDF, IDF, and ash. It also showed a higher density and no deterioration in expansion as compared to the control extrudate, but was darker than the control as a result of the addition of chokeberry pomace, making it more visually appealing than the regular corn extrudates.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app13084818/s1, Table S1: Total color difference ΔE calculated for corn extrudates with addition of fruit pomace.

Author Contributions: Conceptualization, D.G.; methodology, D.G., W.B. and T.Z.; investigation, D.G. and T.Z.; resources, D.G., W.B. and T.Z.; data curation, D.G., W.B. and T.Z.; writing—original draft preparation, D.G. and W.B.; writing—review and editing, D.G. and W.B.; visualization, W.B.; supervision, D.G. All authors have read and agreed to the published version of the manuscript.

Funding: The Research was financed by the Ministry of Science and Higher Education of the Republic of Poland.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: There are no conflict of interest to declare.

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