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The Effect of the Addition of Selected Fruit Pomace Powders and Pectin as Carrier Agents on the Nutritional Value of Freeze-Dried Snacks

Magdalena Karwacka [1,*], Katarzyna Rybak [1], Michał Świeca [2], Sabina Galus [1,*] and Monika Janowicz [1]

[1] Department of Food Engineering and Process Management, Institute of Food Science, Warsaw University of Life Sciences (SGGW-WULS), Nowoursynowska St. 159c, 02-776 Warsaw, Poland
[2] Department of Biochemistry and Food Chemistry, University of Life Sciences in Lublin, Skromna St. 8, 20-704 Lublin, Poland
* Correspondence: magdalena_karwacka@sggw.edu.pl (M.K.); sabina_galus@sggw.edu.pl (S.G.)

Abstract: This study was conducted to analyze the effect of the addition of powdered apple and blackcurrant pomace on the nutritional value, bioaccessibility of polyphenols, and antioxidant activity of freeze-dried fruit and vegetable snacks in comparison to low-methoxyl pectin as a traditional carrier agent. We evaluated sugars, protein, fat, ash, and total dietary fiber contents, as well as content and potential bioaccessibility of polyphenols and antiradical properties. In comparison to snacks with pectin, those with apple pomace powder were richer in carbohydrates and sugars, while snacks with blackcurrant pomace featured significantly higher ($p \leq 0.05$) protein, ash, and fat contents. The material with pectin had the highest content of total dietary fiber. The addition of blackcurrant pomace powder increased the content of potentially bioaccessible polyphenols and enhanced the antiradical properties of the products. The blackcurrant pomace exhibited a more beneficial effect on the nutritional value of the freeze-dried snacks than other carrier agents applied. Nonetheless, further research is needed to determine the effect of the addition of various amounts of pomace powders on some crucial properties, such as dietary fiber and bioactive compounds contents, as well as physicochemical characteristics.

Keywords: freeze-dried snacks; apple pomace; blackcurrant pomace; pectin; protein; sugar content; total dietary fiber; in vitro digestion

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1. Introduction

Consumption of snacks has increased over decades, and this phenomenon is being constantly observed among people of various ages all around the world. The term "snacks" itself has not yet been clearly defined [1], but as was developed by Potter et al. [2], four out of five official definitions established individually by several countries characterized snacks as foods and drinks consumed between main meals, and only one included information that the total calorific value of these meals should not exceed 150 kcal. The meaning of "snacks" also refers to energy-dense and nutrient-poor foods that are packed in small individual portions and can be easily consumed between regular meals [3,4]. Moreover, despite the lack of a universal definition, consumers' perception of such a term is influenced by the potential nutritional value and health disadvantages and features related to time, location, and circumstances of snacking, as well as types of food commonly chosen as snacks [3,4]. Regarding snacking products that are most often seen as unhealthy, there is a global trend connected to consumers seeking more sustainable and conscious food choices, motivated by the spread of a self-care lifestyle and public approval, as opposed to unhealthy snacks. As a consequence, there is a growing branch of the food sector that focuses on the development of more beneficial alternatives for easy and accessible traditional snacks [5]. Reflecting on the scale of snacking popularity, there are surprisingly

few recommendations for in-between meals eating associated with quality and quantity of taken comestibles. Moreover, most of them imply restricting the amount of sweet and salty, high-energy products in favor of less-processed and fresh foods such as fruits, vegetables, or nuts, which help to maintain a nutritious and balanced diet and are suggested to be consumed three to five times a day, depending on the source [2].

Fruits and vegetables are natural sources of valuable nutrients such as dietary fiber and vitamins, along with micro and macro elements, which are crucial components of a healthy and balanced diet. The most recent WHO (World Health Organization) recommendations for both adults and children include consuming at least 400 g of non-starchy fruit and vegetables, preferably allocated into five portions [6]. Unfortunately, the consumption of these products is still insufficient. It is especially noticeable in the case of vegetables, which are less sweet in comparison to fruits, and are therefore perceived as less attractive and consumed not as willingly, particularly by children [7]. Because of their short shelf-life, easy spoilage, and quick overall quality decrease, combined with consumers' constant demands, various aspects of fruit and vegetable processing have been studied comprehensively, including techniques, quality, and development [8]. Moreover, it is also recognized that fresh or processed products have the potential to be considered as sources of some essential nutrients and health-promoting compounds, but a lot of these remain in by-products and residues [9]. Currently, given the pandemic and an increasingly tense geopolitical situation combined with population growth and climate crises occurring around the world, it has been shown that the food industry must search for extraordinary solutions providing access to highly nutritious foods obtained from local goods in case of potential limitations in the supply chain resulting from rising prices, unstable trade, reduced resources, and transport difficulties [10–13]. Thus, fruit and vegetable by-products, such as pomace, have become important parts of scientific research and the novel food development sector [9,14]. Furthermore, there have been only a few attempts at applying fruit pomace as a carrier agent in freeze-dried fruit and vegetable snacks, as reported by Karwacka et al. [15–17] and Ciurzyńska et al. [18]. However, these papers pertain to physical rather than chemical and nutritional properties of the products. Therefore, the novelty of the present study is that we captivated three significant aspects of current food science and technology. The first one relates to food waste management and sustainable product development due to the infusion of fruit pomace as food additives, the second is the choice of freeze-dried fruit and vegetable snacks as a base of the research, and the third and final aspect is the analysis of the impact of pomace addition on chemical composition and nutritional value.

Fruit pomace is a solid residue remaining after juice and cider manufacturing. Generally, it contains up to 85% water, and so there is a risk of microbiological contamination and spoilage; thus, pomace is usually dried and then subjected to further processing [19]. A possible hazard of toxic residues, such as mycotoxins or pesticides, in the pomace has been considered, but the studies conducted on that topic proved that consumption of pomace in small amounts does not put human health in danger. The quality of pomace must be tested before using it as a food ingredient, but in general, a food-grade pomace has been established [20,21]. Most of the bioactive compounds do not migrate to manufactured products and they stay in the solid matter of pomace; therefore, it is rich in polyphenols, organic acids, and minerals, and accordingly has notable antioxidant capacity [19,20,22,23]. These by-products are also characterized by a relatively high content of soluble and insoluble fibers, cellulose, hemicellulose, lignin, and pectin, which induces its water binding and swelling capacity [19,24] and helps extend the feeling of satiety after consumption [25,26]. The chemical character of these compounds requires calcium ions to activate their gelling properties [19,27]; therefore, pomace-enriched products may have a beneficial effect on the overall functioning of the digestive system and mineralization. This makes the infusion of pomace and pure pectin, along with calcium salts, as it demands, into the composition of new products favorable not only in technological aspects but in nutritional aspects as well. Poland has been a leading producer of apples and blackcurrant for many years and many harvests are allocated for processing, which generates a great amount of residues

to manage [28–30]. The physicochemical and nutritional properties of both apple and blackcurrant pomace have already been analyzed several times. It has been recognized that the quality and composition of pomace differ and depend on the quality of raw material, which also varies and is contingent on origin, season, and cultivation method. However, irrespective of the particular characteristics, fruit pomace has a prominent potential of being utilized as a food-enriching component [19,21,29,31,32].

Therefore, we aimed to develop new plant-based snacks and analyze the effect of the addition of powdered fruit pomace (apple and blackcurrant) on the nutritional value, bioaccessibility of polyphenols, and antioxidant activity of freeze-dried fruit and vegetable snacks in comparison to low-methoxyl pectin as a traditional carrier agent stabilizing physicochemical properties of the freeze-dried products. This study will be used to select the features most influenced by various compositions to focus on in future research to evaluate the effect of the addition of pomace as a carrier agent in freeze-dried products.

2. Materials and Methods

2.1. Material

The material examined in this research was freeze-dried carrot–orange–ginger (COG) snacks (Figure 1). Formulations of the material consisted of 60% frozen carrot cubes (Unifreeze Sp. z o.o., Miesiączkowo, Poland), 30% orange juice (Tymbark, Poland), 7.5–8% water, 0.4% fresh ginger purchased at a local market in Warsaw (Poland), and 0.1% calcium lactate (Agnex, Poland). Moreover, three different carrier agents differentiating the material were used. Industrial dried apple pomace powder (AP) (Greenherb, Poland) and dried blackcurrant pomace powder (BP) (Greenherb, Poland) were added in the amount of 2%, whereas the quantity of low-methoxyl pectin (LMP) (Hortimex, Poland) equaled 1.5%. Each carrier agent was used separately. The mixed batches were freeze-dried utilizing an Alpha 1–2 LDplus freeze-dryer (Martin Christ Gefriertrocknungsanlagen GmbH, Osterode am Harz, Germany) at a shelf temperature of 30 °C, chamber pressure of 63 Pa, and condenser temperature of −53 °C for about 48 h. The processing of the snacks was described in detail by Karwacka et al. [17]. An effect of applying such additives on the physical properties of the freeze-dried snacks has already been reported, and, as was described previously, the water content in the freeze-dried snacks in the sequence COG-AP, COG-BP, and COG-LMP was 1.91 ± 0.04%, 2.10 ± 0.26%, and 2.55 ± 0.11% [17].

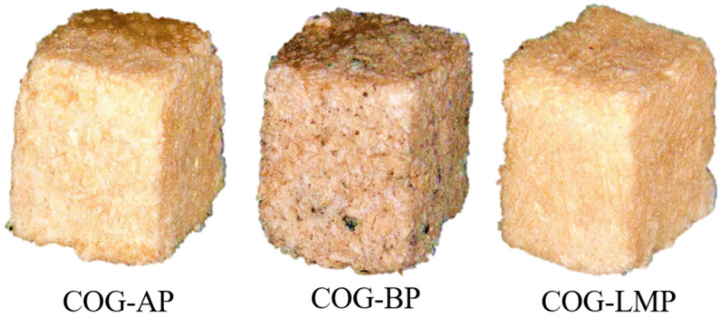

Figure 1. Freeze-dried carrot–orange–ginger snacks obtained with the addition of powdered apple (COG-AP) and blackcurrant (COG-BP) pomace and low-methoxyl pectin (COG-LMP) as carrier agents.

2.2. Analytical Methods

2.2.1. Free Sugar Content Determination

Determination of sugar content was carried out using a high-pressure liquid chromatography method with refractive index detection [33]. HPLC, Waters 2695 Alliance (Waters, Milford, MA, USA) was equipped with a quaternary pump, autosampler, column thermostat, and RI detector. The compounds were separated with a 300 × 6.5 mm Waters Sugar Pak I column with a Sugar-Pak guard column. Before the procedure, freeze-dried

snacks were ground using a basic analytical mill A11 (IKA Laboratory Equipment, Warsaw, Poland), and 0.3 g of the powdered sample was extracted with distilled water at 80 °C for 12 h. Obtained aqueous extracts were filtered using a 0.22 µm PTFE syringe filter, and a volume of 10 µL was injected into the chromatographic system. The glucose, fructose, and sucrose content were calculated based on calibration curves acquired for these compounds' standards (Sigma-Aldrich, Steinheim, Germany).

2.2.2. Protein Content Determination

Protein content in the freeze-dried snacks was determined using the Kjeldahl method. The preparation of the sample consisted of material mineralization. A ground sample of known weight was placed into a mineralization vessel with two tablets of Kjehltabs catalyzer and 12 mL of saturated sulfuric acid. Mineralization was carried out utilizing the Tecator 2020 Digestor (FOSS Analytical, Hillerød, Denmark) at 420 °C. The procedure was performed using the Kjeltec Auto 1035 nitrogen analyzer (Perstorp Analytical Tecator, Malmö, Sweden) equipped with an autosampler, automatic sample dilution system with redistilled water, automatic neutralization system with 33% NaOH solution (VWR International, Gdańsk, Poland), and colorimetric titration system. Nitrogen content was measured by titrating the neutralized sample with 0.1 HCl solution (VWR International, Gdańsk, Poland). Protein content in the freeze-dried snacks was calculated using the N × 6.25 indicator, which portrays an average content of nitrogen in proteins from plant tissue at the level of 16% [34].

2.2.3. Fat Content Determination

Fat content was determined using the Soxhlet method. Fat extraction was conducted using the Soxtec Avanti 2050 Auto Fat Extraction System (FOSS Analytical, Hillerød, Denmark) at 130 °C using petroleum ether (VWR International, Gdańsk, Poland). The first step of the procedure was the extraction of fat in boiling solvent for 30 min. After that, the sample was washed with petroleum ether vapor for 45 min, and then the solvent recovery was carried out. Obtained fat was dried for about 1 h, cooled in a desiccator, and weighed. Fat content was calculated as the ratio of the extracted fat to the initial weight of the sample.

2.2.4. Total Dietary Fiber Content Determination

Determination of total dietary fiber was conducted according to AOAC 985.29 methodology [35] and the 200A Total Dietary Fiber Assay Kit (Megazyme, Wicklow, Ireland). Prior to the test, the following reagents were prepared: phosphate buffer and pH 6, 0.275 M NaOH, 0.325 M HCl, and 78% ethanol, all supplied by VWR International (Gdańsk, Poland). Previously, porcelain crucibles were roasted at 525 °C for 3 h. After cooling, 0.5 g of celite was added to each, wetted with distilled water, and dried at 130 °C to constant weight. After cooling, the crucibles were weighed and stored in a desiccator until use. The procedure started with weighing approximately 1 g of ground material onto the base of the incubation flask in two repetitions, and 50 mL of phosphate buffer pH 6 was added. It was mixed on a magnetic stirrer until a homogeneous suspension was obtained, and then 50 µL of α-amylase (3000 U·mL^{-1}) was added, mixed, covered tightly with aluminum foil, and incubated in a water bath at 90–100 °C for 30 min. After removal from the water bath, the flasks were cooled and the mixtures were increased to pH 7.5 with 0.275 M NaOH solution. When pH was corrected, 100 µL of protease (350 U·mL^{-1}) was added, mixed, and incubated in a shaking water bath at 60 °C for 30 min. After that time, the mixture was cooled and the pH lowered to 4.5 with a 0.325 M HCl solution. With constant stirring, 200 µL of amyloglucosidase (3300 U·mL^{-1}) was added, and then the flasks were covered with foil and incubated again at 60 °C for 30 min. After incubation, 280 mL of 96% ethanol at 60 °C was added to each flask and allowed to precipitate soluble fiber for one hour at an average temperature of 25 °C. The roasted crucibles and flasks with the mixture were placed in the filter module Fibertec 1023 (FOSS Analytical, Hillerød, Denmark). Filtration was then carried out by washing the vessels with ethanol. The crucibles were transferred to

the top of the module, after which the contents were washed three times with 20 mL 78% ethanol, twice with 10 mL 96% ethanol, and twice with 10 mL acetone. The crucibles were dried at 105 °C for approximately 16 h. After cooling in a desiccator, they were weighed. Subsequently, one sample was subjected to protein content determination using the Kjeldahl method, and the other was burnt in a muffle furnace at 525 °C for 5 h. After cooling in the oven, the sample was cooled in a desiccator and weighed. The total fiber content was calculated as the difference between the weight of the dry residue after filtration and the weights of the protein and ash contained in it.

2.2.5. Ash Content Determination

Determination of ash content in the freeze-dried snacks was performed by mineralization of about 1 g of sample in a muffle furnace at a temperature of 525 °C.

2.2.6. Carbohydrate Content Determination

Content of carbohydrates including sugars, specifically non-dietary fiber (non-DF) carbohydrates, was estimated as a difference remaining to 100% after subtraction of water, protein, fat, ash, and total dietary fiber contents [24].

2.2.7. Calorific Value Determination

The calorific value of the freeze-dried snacks was determined utilizing a pressure bomb calorimeter (own construction). Tested material in the form of 1 g pellets, prepared by grinding freeze-dried snacks into a powder and compressing it, was burned in a calorimeter chamber in the atmosphere of pure oxygen. The heat of combustion (gross calorific value) was calculated based on the change in water surrounding the chamber temperature and sample weight by dedicated software.

2.2.8. Polyphenol Content and Antioxidant Properties

Extraction Systems

In vitro digestion procedure

In vitro digestion was performed as described previously [36] with slight modifications. All enzymes and chemical reagents used for the procedure were supplied by Sigma-Aldrich (Poznań, Poland). First, 1 g homogenized samples were subjected to the digestion process after previous hydration in distilled water at 1:1. The first step of the enzymatic digestion was an oral phase that included adding 1.4 mL of simulated saliva stock solution (SSFESS), 0.39 mL of distilled water, 0.01 mL of 0.3 M sodium chloride, and 0.2 mL of α-amylase (1500 U·mL^{-1}). Incubation of the samples was conducted in the dark, continuously shaking at 37 °C for 2 min. For the gastric phase, the obtained bolus was blended with 3 mL of simulated gastric stock solution (SGFESS), 0.278 mL distilled water, 0.002 mL of 0.3 M sodium chloride, 0.08 mL of 1 M hydrochloric acid, and 0.64 mL of porcine pepsin (25,000 U·mL^{-1}). Then, the matrix was incubated at 37 °C for 120 min, as before with continuous shaking and in a dark place. The last phase, intestinal digestion, consisted of mixing gastric chyme with 4.4 mL of simulated intestinal stock solution (SIFESS), 0.524 mL distilled water, 0.06 mL of 1 M sodium hydroxide, 0.03 M of 0.3 M sodium chloride, 1 mL of aqueous bile extract (160 mM), and 2 mL of pancreatin (800 U·mL^{-1}). Further incubation was performed as per the previous step, at the temperature of 37 °C for another 120 min, with continuous shaking and in the dark. During digestion, pH is a crucial factor for a proper course of the procedure, and it should be 7 for the oral and intestinal phases and 3 for the gastric digestion phase. Therefore, pH was controlled and corrected using 1 M sodium hydroxide and 1 M hydrochloric acid. After digestion, the samples were centrifuged (15 min, 6900× *g*) and the supernatants were mixed with an equal volume of methanol to stop enzyme activity.

Chemical extraction

The samples (500 mg) were extracted three times using a mixture of methanol:acetone:water (4:4:2, *v*/*v*/*v*), pH 5 (adjusted with 1 M HCl), ensuring high stability of low-molecular-weight antioxidants [37,38]. The sample was extracted with 5 mL of solvent for 30 min at room temperature using a multi-rotator (RS-60, Biosan, Riga, Latvia) (300 rpm) and centrifuged (15 min, 6000× *g*), and the pellets were re-extracted. The supernatants from all steps were combined and stored for further analysis. The extraction was performed in duplicate for all freeze-dried samples, and obtained extracts were used for the determination of total polyphenol content and antioxidant activity of material before digestion.

Total Polyphenol Content Analysis

The content of total polyphenols was determined using Folin–Ciocalteu reagent [39] and expressed as gallic acid equivalents (GAE) in mg per g. First, 10 µL of extract and distilled water were dispensed into 96-well plates. For the blank test, the sample extract was substituted with 10 µL of extraction reagent. To the prepared mixtures, 40 µL of 5-fold diluted Folin–Ciocalteu reagent (Sigma-Aldrich, Poznań, Poland) was added. Samples were mixed, and after 3 min, 250 µL of 10% sodium carbonate aqueous solution was added. Mixed samples were incubated for 30 min in a dark place. After that, the absorbance was measured using a plate reader (Multiskan Sky, Thermo Electron Co., Waltham, MA, USA) at a wavelength of 725 nm.

2.2.9. Antioxidant Activity against ABTS and DPPH Radicals

Abilities to quench ABTS and DPPH radicals were determined as described previously [33,40,41]. Free radical solutions were prepared 24 h before the analysis by dissolving 25 mg of 2,2-diphenyl-1-picrylhydrazyl (DPPH) with 99% methanol up to 100 mL and 38.4 mg of (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) in 10 mL of distilled water with the addition of 6.6 mg of potassium persulfate. Directly before the analysis, the prepared stock solutions were diluted with 80% ethanol to obtain absorbance in the range of 0.68–0.72. All chemical reagents were supplied by Sigma-Aldrich (Poznań, Poland).

In order to determine antioxidant activity, 10 µL of the extracts were mixed in a 96-well plate with 250 µL of the free radical solution. The plate was shaken and incubated in a dark place for 2 h, and subsequently, absorbances of the samples were measured using a plate reader (Multiskan Sky, Thermo Electron Co., Waltham, MA, USA) at a wavelength of 734 nm and 515 nm for the ABTS and DPPH test, respectively. The antioxidant activity was expressed as Trolox equivalents in mg Trolox/g.

2.2.10. The Relative Bioaccessibility Index (REF)

The relative bioaccessibility index was determined to present the relationships between biologically active compounds and antioxidant activities in terms of their bioaccessibility [42]. It was calculated for polyphenols and antioxidant activities as follows:

$$\text{REF} = \text{PD (AD)}/\text{PC(AC)} \quad (1)$$

where PD is the concentration of the polyphenols in the digests, PC is the concentration of polyphenols in the extract obtained with organic solvents, AD is the selected antioxidant activity (ABTS, DPPH) in the digests, and AC is the selected antioxidant activity (ABTS, DPPH) in the extract obtained with organic solvents.

2.3. Statistical Analysis

Obtained results (n = 9, mean ± SD) were statistically analyzed using Statistica 13.3 software (TIBCO Software, Palo Alto, CA, USA). One-way analysis of variance ANOVA and Tukey's test at $p \leq 0.05$ were performed.

3. Results

3.1. Carbohydrates and Sugar Content

Carbohydrates incorporate all sugars, oligosaccharides, and polysaccharides found in food [43], and in the case of this study, total non-dietary fiber carbohydrate content includes sugars and digestible carbohydrates, except dietary fiber. Based on a statistical analysis of the obtained results shown in Table 1, the addition of dried apple pomace powder made the total non-DF carbohydrate content of the freeze-dried snacks higher in comparison to other variants of the snacks, which were characterized by about 6–6.5% lower and statistically the same content. Accordingly, a similar tendency was observed in the case of glucose and fructose content, which were a few percent and significantly greater ($p \leq 0.05$) in the COG-AP sample than in COG-BP and COG-LMP, which also were similar. On the other hand, each snack's sucrose content significantly differed ($p \leq 0.05$), and both extreme results were determined: the lowest for the freeze-dried snacks with apple pomace powder and the highest for that with blackcurrant pomace powder. As a consequence, total sugar content, including all of the investigated sugars (glucose, fructose, and sucrose), was also significantly higher ($p \leq 0.05$) in the COG-AP sample (45.76%), while for COG-BP and COG-LMP samples, it was estimated up to 43.50% and 43.77%. The presented findings correspond to the literature that confirms only a slight part of carbohydrates not belonging to a dietary fiber in blackcurrant pomace [24,44], which may justify the resemblance of the COG-BP and COG-LMP non-DF carbohydrates profile. On the contrary, previous papers reported relatively high content of such constituents in dried apple pomace [19,21], which also is in an agreement with the outcomes of this study.

Table 1. Sucrose, glucose, fructose, and total non-dietary fiber (non-DF) carbohydrate content in the freeze-dried carrot–orange–ginger (COG) snacks obtained with the addition of powdered apple (AP) and blackcurrant (BP) pomace and low-methoxyl pectin (LMP) as carrier agents.

Sample	Total Non-DF Carbohydrates (%)	Sucrose (%)	Glucose (%)	Fructose (%)
COG-AP	60.37 ± 0.79a	20.28 ± 0.09c	11.30 ± 0.15a	14.18 ± 0.36a
COG-BP	55.77 ± 0.61b	22.78 ± 0.08a	9.66 ± 0.38b	11.06 ± 0.06b
COG-LMP	55.98 ± 0.27b	21.79 ± 0.32b	10.35 ± 0.08b	11.63 ± 0.09b

Means (±SD; $n = 9$) for analysis followed by different small letters are significantly different ($p \leq 0.05$).

3.2. Protein Content

Figure 2 presents protein content determined in the freeze-dried carrot–orange–ginger snacks. The snacks with the addition of apple pomace powder contained 7.09% protein. Those with blackcurrant pomace powder contained 9.06% protein, and those with pectin, 6.64%. Statistical analysis of the obtained results indicated that the composition of samples with the addition of blackcurrant pomace (COG-BP) as a carrier agent was greater in protein content compared to the other two variants. The percentage of the protein in snacks with apple pomace powder (COG-AP) was also slightly higher than in products with low-methoxyl pectin (COG-LMP), but there was no significant difference ($p \leq 0.05$) between the two of them. Given the carrier agents as the only factors differentiating formulations of the examined snacks, such results indicate that blackcurrant pomace powder used as an additive in this research was a richer source of protein than both apple pomace powder and low-methoxyl pectin. Plant-based products, including fruits, vegetables, and their preserves, are recognized as low-protein foods, and for this reason, any attempt to enhance their value could be appreciated from a nutrition point of view [45,46]. Its importance is emphasized especially acknowledging concerns related to plant-based diets and nutrient deficiencies that may result from significantly lower ($p \leq 0.05$) absorbability of protein originating from plant sources in contrast to animal protein [46].

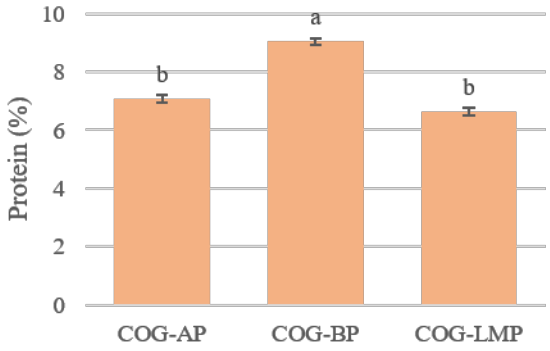

Figure 2. Protein content in the freeze-dried carrot–orange–ginger (COG) snacks obtained with the addition of powdered apple (AP) and blackcurrant (BP) pomace and low-methoxyl pectin (LMP) as carrier agents. Means (±SD; n = 9) for analysis followed by different small letters are significantly different ($p \leq 0.05$).

3.3. Fat Content

Of all the basic compounds in food, fat accounts for notably higher energetic value and relatively low satiety fulfillment [47], and so high-fatty products are energy-dense and often classified as unhealthy products, the consumption of which should be limited, especially for snacks [48,49]. As can be seen from Figure 3, each type of carrier agent used in the study affected fat content in the freeze-dried fruit and vegetable snacks; its quantity was in the range of 0.64–2.04%. The lowest value was observed for the COG-LMP sample with the addition of pure hydrocolloid, and the highest was for that with blackcurrant pomace. We observed that the infusion of fruit pomace increased fat content in the obtained products, which complies with the literature, according to which fruit pomace contains fat originating from seeds appearing in the mass of a pomace. Advantageously, oils obtained from fruit seeds consist mostly of poly- and mono-unsaturated fatty acids, including those essential for humans, e.g., linoleic and α-linolenic acids [50–52]; therefore, fortifying food products with fruit pomace may have an even more beneficial effect on human health due to the composition of fat.

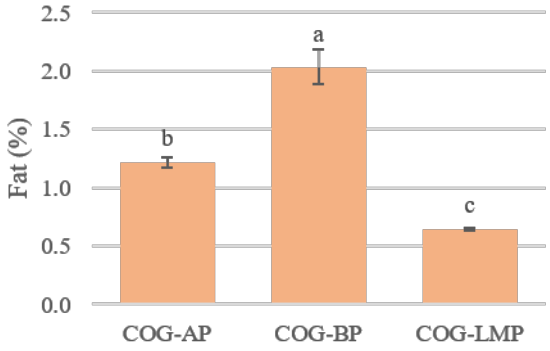

Figure 3. Fat content in the freeze-dried carrot–orange–ginger (COG) snacks obtained with the addition of powdered apple (AP) and blackcurrant (BP) pomace and low-methoxyl pectin (LMP) as carrier agents. Means (±SD; n = 9) for analysis followed by different small letters are significantly different ($p \leq 0.05$).

3.4. Ash Content

The term ash in food products demonstrates all of the mineral residue remaining after the total disintegration of organic compounds, which usually is executed through thermal combustion. The more inorganic micro- and macro-elements accommodate a food, the higher its ash content [53,54]. Results of ash content determination are shown in Figure 4. Applied carrier agents significantly affected ($p \leq 0.05$) this parameter. In this case, freeze-dried snacks with the addition of apple pomace powder (COG-AP) and

blackcurrant pomace powder (COG-BP) were characterized by the lowest (4.81%) and the highest (7.14%) amounts of ash, respectively, and low-methoxyl pectin infusion placed the result obtained for the COG-LMP sample right in the middle (5.99%). Thus, it may be assumed that of all the carrier agents used, apple pomace contained the lowest amount of inorganic compounds, while blackcurrant pomace had the greatest. However, it must be emphasized that the composition of plant material, such as fruits and vegetables and thus their by-products, differs and fluctuates depending on variety, maturity level, as well as storage time and conditions. Moreover, the tendencies observed for ash content changes are not consistent and strongly dependent on the material [55–57]. On the other hand, the high content of ash in pectin indicates its pollution and may disturb gelling properties [58].

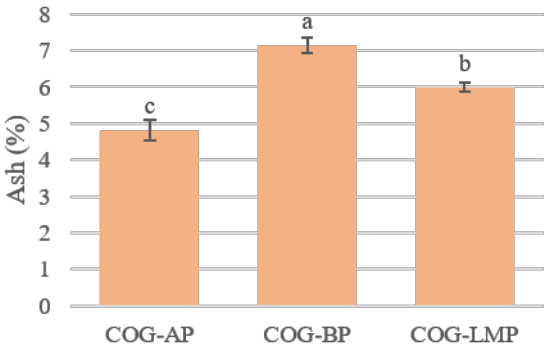

Figure 4. Ash content in the freeze-dried carrot–orange–ginger (COG) snacks obtained with the addition of powdered apple (AP) and blackcurrant (BP) pomace and low-methoxyl pectin (LMP) as carrier agents. Means (±SD; $n = 9$) for analysis followed by different small letters are significantly different ($p \leq 0.05$).

3.5. Total Dietary Fiber Content

Dietary fiber consists of polysaccharides, oligosaccharides, and lignin—that is, high-molecular-weight components of edible plant structure which resist digestion and absorption in the human organism, simultaneously having a beneficial effect on the overall functioning of the digestive system and digestion process itself, as well as in the prevention of several chronic diseases [59,60]. Figure 5 portrays the total dietary fiber (TDF) content in the freeze-dried snacks, which ranged from 23.90% to 24.60% and up to 29.51%. As can be seen in the figure, the sample with the addition of the pure hydrocolloid carrier agent (COG-LMP) featured significantly higher ($p \leq 0.05$) content of the TDF, and so snacks with both types of pomace powder were characterized by about 5–6% lower values of that parameter. This is consistent with previous literature data that claim pectin as one of the components defined as soluble dietary fiber [59]. According to the literature, dried fruit pomace may contain even up to 90% of TDF, but it more likely oscillates at a level below 60%, depending on the material [24,61]. There were also no statistically significant differences ($p \leq 0.05$) between TDF content in COG-AP and COG-BP snacks, which implies that either AP or BP powder used in this study incorporated total dietary fiber at a similar level. Despite expected degradation of high-molecular-weight dietary fiber carbohydrates to lower forms and sugars, Reißner et al. [62] found that the application of hydrothermal and mechanical processing causes favorable changes in the functionality of the blackcurrant pomace, but no significant ($p \leq 0.05$) transformation of the chemical composition (dietary fiber and sugar contents) of the material was observed, which is beneficial in terms of repetitive quality of fortified foods. Therefore, it can be assumed that processing does not affect the composition of a pomace, at least in terms of the carbohydrate profile.

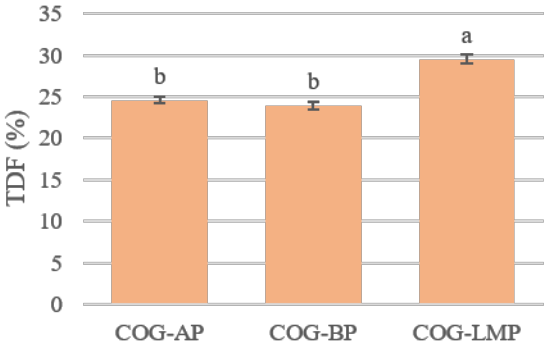

Figure 5. Total dietary fiber (TDF) content in the freeze-dried carrot–orange–ginger (COG) snacks obtained with the addition of powdered apple (AP) and blackcurrant (BP) pomace and low-methoxyl pectin (LMP) as carrier agents. Means (±SD; n = 9) for analysis followed by different small letters are significantly different ($p \leq 0.05$).

3.6. Calorific Value

The calorific value of the freeze-dried snacks is shown in Figure 6. It is expressed as energy of the material combustion estimated for 100 g of the product in order to match the usual form placed in food product packaging. However, the freeze-dried snacks were prepared in the shape of bars using 2 × 3 × 10.5 cm rectangular silicone molds, so one serving of the snacks was considered one bar of 10 g; thus, the approximate amount of energy delivered with the consumption of the products equals 10% of demonstrated values. According to this, the energetic values of the snacks in the sequence COG-AP, COG-BP, and COG-LMP were equal to 429.46, 433.66, and 386.78 kcal/100 g of the product, and consequently, 42.95, 43.37, and 38.68 kcal per serving, respectively. The infusion of fruit pomace significantly increased ($p \leq 0.05$) the calorific value of the products by approximately 11.6% in comparison to snacks with low-methoxyl pectin (COG-LMP). Such an effect may have been a consequence of higher sugar and fat content, which fruit pomace typically comprises [19,24], and so they were introduced into the composition of the snacks with the pomace powder. Nevertheless, even though the content of particular compounds differed contingent on the type of additive used, there was no significant difference ($p \leq 0.05$) between snacks with apple (AP) and blackcurrant (BP) pomace.

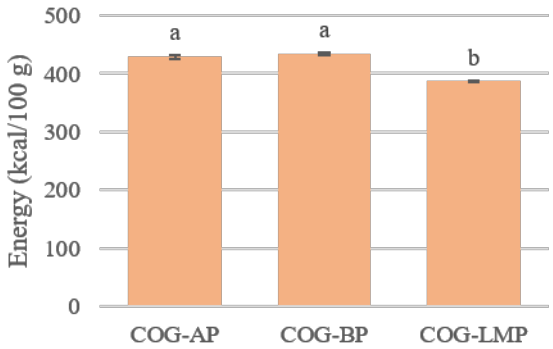

Figure 6. Calorific value of the freeze-dried carrot–orange–ginger (COG) snacks obtained with the addition of powdered apple (AP) and blackcurrant (BP) pomace and low-methoxyl pectin (LMP) as carrier agents. Means (±SD; n = 9) for analysis followed by different small letters are significantly different ($p \leq 0.05$).

The approximate composition of apple, blackcurrant, and any type of fruit or vegetable pomace is hard to assess, considering their diversity and dependence on internal and external factors. Recently, Wladbauer et al. [19] collected data from various scientific reports on apple pomace composition and compiled a diagram portraying an average composition of dried apple pomace. According to the data, dried apple pomace contains

36.89% total dietary fiber, 7.51% glucose, 15.96% fructose, 8.36% sucrose, 3.37% protein, 1.88% ash, and 0.38% polyphenols, vitamin C, and vitamin E combined. Usman et al. [63] also determined the content of some nutrients in dried apple pomace powder. They obtained 1.95% protein, 3.01% fat, 10.85% fiber, 1.50% ash, and 9.75 mg/g of polyphenols. Skinner et al. [21], on the other hand, provided an approximate composition of fresh apple pomace as 1.1–3.6% fat, 2.7–5.3% protein, 4.4–47.3% total dietary fiber, and 44.5–57.4% carbohydrates, including 44.7% fructose and 18.1–18.3% glucose. The authors emphasized the inadequacy of such data and the limitations resulting from the diversity of the material and the lack of comprehensive research. Lyu et al. [64] also pointed out the differences between the composition of apple pomace in various reports, and added processing techniques to the list of factors affecting the quality of the by-products. Nevertheless, the estimation of blackcurrant pomace composition faces similar issues. The dry matter of blackcurrant pomace examined by Reißner et al. [62] consisted of 71.31% dietary fiber, 10.42% protein, 4.22% of fat, 7.28% fructose, and 3.96% glucose. Another paper by Reißner et al. [24] reported that the contents of fat, protein, ash, total dietary fiber, and carbohydrates in blackcurrant pomace powder were 20.21%, 15.71%, 2.66%, 59.13%, and 2.20%, respectively. Additionally, Déniel et al. [44] established that dried blackcurrant pomace comprised 61.7% fiber, 4.5% fat, 16.9% proteins, and 14.8% lipids. Considering all referred data, it may be concluded that in general, blackcurrant pomace powder contains more protein and fat than apple pomace powder, which is consistent with the results obtained in this study. Moreover, differences in the composition of the freeze-dried snacks were determined by the composition of the additives used, but given the diversity of the material, the results may not be repetitive or representative of different batches of the raw material.

There are not many similar products in the Polish market, but one type of commercially available freeze-dried snacks in the form of bars can be found [65]. An average formulation of these bars contains fruits (about 31%), concentrated fruit juices, carob tree extract, maltodextrin, inulin, and pectin, and a singular serving of the snack proposed by the producer is a 10 g bar. The nutritional facts presented on the package state that 100 g of the product delivers 30–34 kcal, 0.7–3.2 g of protein, 0.1–1 g of fat, 53–69 g of carbohydrates (including 39–51 g of sugars), and 28–36 g of dietary fiber. The data were collected based on nutritional fact tables for four flavor variants of the freeze-dried snacks and suggest that the research material of this study is comparable to the commercial products. Nonetheless, given the resemblance of the composition of both commercial products and the snacks examined in this study, conducted research revealed that snacks with fruit pomace powders have about 20–25% higher calorific values than an average commercial snack. However, there are neither vegetable nor fruit pomace-enriched alternatives to be found, and all the freeze-dried bars available on the Polish market were developed on a base of fruits and hydrocolloids.

Recently, Janowicz et al. [66] reported a mathematical assessment of the energy and nutritional value of multi-layer freeze-dried vegetable snacks structured with various hydrocolloids (sodium alginate and a blend of carob and xanthan gums). Given products featured remarkably lower calorific values (14.5–16.5 kcal/10 g), contrary to the snacks investigated in this research. The difference may have resulted from methods used in both studies, because the outcomes of the mentioned one were strictly theoretical and based on nutritional tables that do not include all of the components of the formulations. Considering the size of said differences, they indicate that fruit components are responsible for higher energy delivery. Furthermore, as was reported by Janowicz et al. [66], freeze-dried vegetable snacks also consisted of 7.1–8.3% protein, 1.2–1.5% fat, 26–30% carbohydrates (including sugars), and 8–10% total dietary fiber deriving from infused vegetables and herbs, but the study did not consider hydrocolloids, so the presented TDF content seems to be underestimated.

3.7. Polyphenol Content and Antiradical Properties

Total polyphenol content and antiradical activity of the freeze-dried snacks before and after subjection to in vitro digestion are presented in Table 2. There were no statistically significant differences ($p \leq 0.05$) in the total polyphenol content in the extract obtained with organic solvents (CHE); however, the replacement of low-methoxyl pectin (COG-LMP) with blackcurrant pomace powder (COG-BP) caused an increase of about 10%. The highest content of polyphenols in the potentially bioaccessible fraction (BE) was recorded in COG-BP (an increase of 44% compared to COG-LMP). Polyphenols from snacks were relatively bioaccessible—REF values ranged from 1.47 to 1.90 for COG-LMP and COG-BP, respectively. In this case, the potentially bioaccessible fractions were characterized by significantly higher ($p \leq 0.05$) activity when compared to the extracts from "chemical" extraction. The highest activity was recorded for COG-BP, while COG-AP and COG-LMP exhibited lower activity by approximately 50%. The opposite was previously reported by Karwacka et al. [16], who obtained almost triplicate content of polyphenols in freeze-dried vegetable snacks with apple pomace powder compared with the material with sodium alginate as a hydrocolloidal carrier agent, which induced a similar tendency when it comes to antioxidant activity against DPPH radicals, while in this study, the content of TPC was reflected in the ability to quench ABTS radicals. Moreover, the ability to scavenge DPPH radicals was higher in the extract obtained with organic solvents than in counterparts from digestion in vitro. Compounds able to reduce DPPH radicals were poorly bioaccessible in vitro (REF < 1). Similar behavior was previously reported for the highly pigmented and hydrophilic antioxidants, where antiradical properties were better reflected by ABTS assay than DPPH assay [67]. Thus far, a realization of polyphenols from AP was confirmed by Nayak et al. [68], who recorded c.a. 3-fold higher content in potentially bioaccessible fraction, but similarly to our studies, those extracts were characterized by a lower ability to quench DPPH radicals. Blackcurrant pomace is an excellent source of polyphenols, especially anthocyanins [32], supporting increased polyphenol content and the ability to quench ABTS radicals observed after the replacement of LPM with this material. Although anthocyanins from BP are characterized by low stability during digestion [69], it seems that the matrix of the snacks protected them. As reported by Diez-Sánchez et al. [70], when it comes to the bioaccessibility of polyphenols, the addition of blackcurrant pomace into a model food matrix increases their bioaccessibility in comparison to phenolic extracts, which is also connected to the creation of greater complexes with other constituents of the food models, such as proteins, showing a protective effect on polyphenols during in vitro digestion. Therefore, direct quantification of final effects observed in the extracts from digestion in vitro is difficult because they resulted from many factors, including the release of the compounds from the matrix, degradation thereof, and interactions.

Table 2. Polyphenols and antiradical properties of the freeze-dried carrot–orange–ginger (COG) snacks obtained with the addition of powdered apple (AP) and blackcurrant (BP) pomace and low-methoxyl pectin (LMP) as carrier agents.

Sample	TPC (mg GAE/g)			ABTS (mg TE/g)			DPPH (mg TE/g)		
	CHE	BE	REF	CHE	BE	REF	CHE	BE	REF
COG-AP	3.36 ± 0.37c	5.51 ± 0.14b	1.64	3.23 ± 0.25cd	6.21 ± 0.40b	1.92	1.19 ± 0.02b	0.47 ± 0.11d	0.40
COG-BP	3.73 ± 0.29c	7.08 ± 0.05a	1.90	3.58 ± 0.29c	9.33 ± 0.28a	2.60	1.66 ± 0.09a	0.63 ± 0.09c	0.38
COG-LMP	3.41 ± 0.28c	5.01 ± 0.41b	1.47	3.03 ± 0.14d	6.00 ± 0.46b	1.98	1.50 ± 0.10a	0.65 ± 0.13c	0.43

CHE—the extract obtained with organic solvents; BE—the extract obtained after digestion in vitro; REF—the relative bioaccessibility index; GEA—gallic acid equivalents, TE—Trolox equivalents. Means (±SD; n = 18) for analysis followed by different small letters are significantly different ($p \leq 0.05$). CHE and BE results were analyzed together.

4. Conclusions

The composition of the freeze-dried carrot–orange–ginger snacks obtained with the addition of apple and blackcurrant pomace and low-methoxyl pectin as carrier agents was successfully evaluated. The replacement of pectin with apple pomace powder increased carbohydrate and sugar content, while blackcurrant pomace increased protein, ash, and fat content. None of the used pomace powders enhanced the total dietary fiber content in the snacks to exceed or even equal the level of the snacks obtained with pectin. Moreover, the addition of blackcurrant pomace powder caused an increase in the bioaccessible fraction of polyphenols, and as a consequence, enhanced the antiradical properties of the products, thanks to the thermal stability of the anthocyanins. On the basis of the presented results, blackcurrant pomace powder may be established as having a more beneficial effect on the composition and nutritional value of the freeze-dried snacks than apple pomace powder, or even the most beneficial effect among all the applied carrier agents. However, it must also be considered that because of the diversity of the raw material quality, the results obtained in this research may not be repetitive when using different products, but the trends may be maintained. The use of pomace powders as food additives may facilitate more sustainable and economically viable food processing. Nonetheless, further research is needed to evaluate the impact of various types of fruit pomace on the sensory profile of the snacks and to determine the effect of the addition of various amounts of pomace powders on some of the crucial properties, such as dietary fiber and bioactive compound content. Conducting industrial or semi-industrial experiments would also be interesting, providing more useful data and allowing the verification of the possibility of pomace use in practice, and a comparison of the quality of products manufactured in various ways.

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