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Nutritional Value, Physical Properties, and Sensory Quality of Sugar-Free Cereal Bars Fortified with Grape and Apple Pomace

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Abstract: Cereal bars are so-called convenience foods. Consumers value these products as a healthier alternative to traditional chocolate bars. Since these snacks usually contain added dried fruit, they have high potential for the utilisation of waste materials from the fruit industry. The study aimed to determine the effect of fortification of cereal bars with grape and apple pomace on their nutritional value, physical properties, and sensory quality. The control recipe was modified by replacing 10 or 20 g of sultanas with apple or grape pomace. The fortification with these food by-products resulted in a significant increase in the moisture content of the products, an increase in soluble fibre content, and a decrease in the level of antioxidant compounds. The strength of the cereal bars supplemented with grape and apple pomace increased. In addition, the panellists noticed a colour difference compared to the unmodified product ($2 < \Delta E < 5$). A positive effect of the addition of the fruit pomace on the visual characteristics of the cereal bars was also observed. No changes were observed in the tastiness of the product. On the other hand, the aroma of the modified products and the texture of the bars containing the apple residue were less acceptable. In conclusion, cereal bars containing grape pomace and up to 10 g of apple pomace are characterised by high soluble dietary fibre content and desirable sensory and mechanical properties and are therefore recommended for industrial production.

Keywords: conventional food; cereal bars; fruit industry; food by-products

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1. Introduction

A diet rich in fruit and vegetables plays an important role in the prevention of oxidative stress-related diseases. Such disorders are most often caused by a poor diet consisting of processed foods, alcohol consumption, or smoking. This leads to an overproduction of free radicals in the body, resulting in accelerated ageing processes and the development of cancer, atherosclerosis, stroke, and Parkinson's or Alzheimer's disease. The likelihood of these diseases can be significantly reduced by consuming fruit containing antioxidant compounds, such as polyphenols, carotenoids, or ascorbic acid. Introducing fresh fruit into the diet may be the most effective way of supplying the aforementioned components to the body [1,2]. However, today's lifestyle of the typical consumer makes the use of unprocessed foods quite problematic. Thus, there is a growing interest in foods that are convenient, yet healthy and minimally processed. Consumers are increasingly turning to natural juices (NFC—Not From Concentrate). The scale of their production is also increasing, which in turn results in an increasing amount of post-production waste, i.e., pomace [3,4].

Fruit residues contain large amounts of valuable nutrients. For example, grape residues have been shown to contain 55.6 g of total dietary fibre per 100 g of dry mass and almost 13% of protein in dry mass [5]. They are also an important source of polyphenols [6]. The main phenolic constituents of grape pomace are anthocyanins, flavanols, and stilbenes. The total polyphenol content ranges from 0.68 to 0.75 mg GAE/100 g of dry mass and the anthocyanin content varies from 84.4 to 131 mg/100 g of dry mass [7]. Similarly, apple pomace has high content of antioxidant substances. Schieber et al. (2003) [8] showed that freeze-dried apple pomace extract contained 117.6 mg/kg phenolic compounds. In addition, apple residue is a source of pectin (0.66 g per 100 g fresh weight) and dietary fibre (2.33 g per 100 g fresh weight) [9,10].

Besides the high level of active ingredients, the fruit pomace by-product still contains a high amount of water and is a perishable material. Therefore, it must be processed to be protected from microorganism growth and prepared for storage and subsequent consumption. Properly processed fruit residues can serve as a raw material for the extraction of specific active substances [6] or can be used as an additive in various types of products. The addition of by-products to food can increase its nutritional value. However, unfavourable changes in the physical and organoleptic properties of the products may pose a problem. Numerous studies on the extraction of active ingredients from expeller or fortification of food with residues from the food industry have recently been conducted [11–16]. So far, the research has mainly been focused on the possibility of using plant residues for the fortification of basic products, such as pasta or bread. However, there is not enough information on the possibility of using by-products to produce convenience foods, including cereal snacks. Cereal bars are an interesting alternative for the management of fruit pomace. They are valued by consumers for their simple natural composition. Among cereals, oats are the most widely used to prepare cereal bars due to the high quality and content of protein, predominance of unsaturated fatty acids, and dietary fibre composition. Oat grain also contains significant amounts of soluble phenolic compounds, β-glucans, minerals, and vitamins, including fat-soluble vitamin E. The high dietary value of oat grain is reflected in its suitability for the production of functional foods [17,18]. However, the use of oats increases the water absorption of the dough and increases its softening. Additional incorporation of by-products of the fruit industry may result in a significant change in the structure and strength of the products obtained.

The aim of this study was to determine the effect of fortification of cereal bars with grape and apple pomace on their nutritional value, physical properties, and sensory quality.

2. Materials and Methods

2.1. Material

The basic raw materials used for the study were apples (Jonagold variety) and dark stone grapes (Attila variety) purchased from a local supermarket. In order to obtain pomace, the fresh fruit was subjected to pressing using a Sana Juicer by Omega EUJ-707 slow-speed juicer. The leftover apples and grapes were dried in a POL-EKO, SLN 15 STD laboratory dryer at 60 °C (until the desired moisture content of 12 ± 1% was achieved) and then crushed in a Chemland FW100 laboratory grinder.

The recipe composition of the sugar-free cereal bars is shown in Table 1. The control recipe was modified by replacing 10 or 20 g of sultanas with apple and grape pomace.

2.2. Preparation of Dough and Baking Bars

Before preparing the dough, the oatmeal, barley, rye, seeds, and coconut chips were ground in a Chemland FW100 laboratory grinder. The bananas were ground in a KENWOOD MAJOR classic blender. The dry ingredients were combined and mixed thoroughly, and the remaining food by-products were incorporated. The dough was kneaded for 5 min using the KENWOOD food processor. The prepared dough was placed in 100 × 25 mm silicone moulds. The bars were baked in a Hounö KD 8940 Randers oven at 180 °C for 20 min. After the heat treatment, the bars were left to cool. Next, they were placed in sealed plastic containers and stored at ambient temperature (23 ± 1 °C) before further testing.

Table 1. Recipe composition of the cereal bars.

Sample	Component [g]												
	Oatmeal Flakes	Barley Flakes	Rye Flakes	Sesame Seeds	Sunflower Seeds	Almonds	Pumpkin Seeds	Coconut Chips	Peanut Cream	Fresh Bananas	Sultanas	Grape Pomace	Apple Pomace
CB	140	20	20	10	10	10	10	10	70	180	50	-	-
G1	140	20	20	10	10	10	10	10	70	180	40	10	-
G2	140	20	20	10	10	10	10	10	70	180	30	20	-
A1	140	20	20	10	10	10	10	10	70	180	40	-	10
A2	140	20	20	10	10	10	10	10	70	180	30	-	20

CB-control bars; G1-bars with 10 g grape pomace addition; G2-bars with 20 g grape pomace addition; A1-bars with 10 g apple pomace addition; A2-bars with 20 g apple pomace addition.

2.3. Determination of Moisture

The moisture content was determined according to the standard method [19]. The bars were crushed before measurement. An approximately 2 g sample of the material was dried at 130 °C until no weight loss was observed. The process was carried out using a laboratory dryer (POL-EKO Aparatura, type SLN 15 STD, Wodzisław, Poland). The test was performed in triplicate.

2.4. Determination of Polyphenol Content

To determine the polyphenol content, crushed bar samples were extracted with 80% methanol [12] and then centrifuged for 15 min at 5800 RPM. Total polyphenol content was determined using the Folin-Ciocalteau method [20]. Absorbance was read at 765 nm on a Helios Omega UV-Vis spectrophotometer (Thermo Scientific, Waltham, MA, USA). A calibration curve was performed using gallic acid. Results were expressed as mg gallic acid per 1 g dry weight of the sample. The determinations were performed in triplicate.

2.5. Determination of Dietary Fibre Content

The determination of dietary fibre was carried out using the weight method (AACC 32-05, AACC 32-21, AOAC 991.43, AOAC 985.29) [19,21]. The test sample was digested with the thermostable α-amylase, pepsin, and pancreatin enzymes. Next, the undigested residue of insoluble dietary fibre (IDF) and, after precipitation from the supernatant solution, soluble dietary fibre (SDF) was determined by weight. Total dietary fibre (TDF) was calculated as the sum of the three above. The test was performed in triplicate.

2.6. Determination of Mechanical Strength

The mechanical strength of the bars was determined using a Zwick/Roel Z0.5 testing machine. Inches of the product were placed on stationary wedge supports (40 mm spacing). Three-point breaking tests were carried out at a speed of 5 mm·min^{-1} using a wedge-breaking element. The test was conducted until complete failure of the material, i.e., a 40% decrease in the maximum force recorded during the test. The tests were performed in five repetitions. The maximum force recorded by the testXpert II v3.5 software was taken as the final result.

2.7. Determination of Colour

A 3Color SF80 spectrophotometer (light source D65, observer 10°, measuring head aperture 8 mm) was used to analyse the colour parameters. The parameters measured were: L^*—describing the brightness (0 = white and 100 = black), a^*—describing the colour change from green (−) to red (+), and b^*—describing the colour change from blue (−) to yellow (+).

The total colour change ΔE was also calculated. The determinations were performed in five replicates.

2.8. Sensory Analysis

The bar samples were assessed by a panel of 52 semi-trained team members. They were trained in the descriptive aspects of the test. The consumers assessed the appearance, aroma, consistency, and palatability of the bars. The participants were also asked to rate the product overall. The results were presented in a 5-point structural scale (from 1—"dislike very much" to 5—"like very much"). The following criteria were taken into account when selecting the panellists: good health, non-smoker, not allergic to peanuts and almonds, and consenting to participate in the study. The evaluation was carried out 24 h after baking in a laboratory with LED lighting and room temperature. The panellists were served mineral water as a neutralising agent. A random order of serving the samples was adopted.

2.9. Statistical Analysis

The results were statistically analysed using Statistica 12 software (StatSoft Inc., Tulsa, OK, USA). The distribution of the data was checked for normality by performing the Shapiro–Wilk normality test at an alpha level of 0.05. A significance level of $\alpha = 0.05$ was used for inference. ANOVA extended post hoc analysis based on the Tukey test was used to determine the significance of differences.

3. Results and Discussion

The photograph (Figure 1) presents cereal bars with the addition of fruit pomace. The products obtained were characterised by different nutritional compositions and different physical and sensory properties.

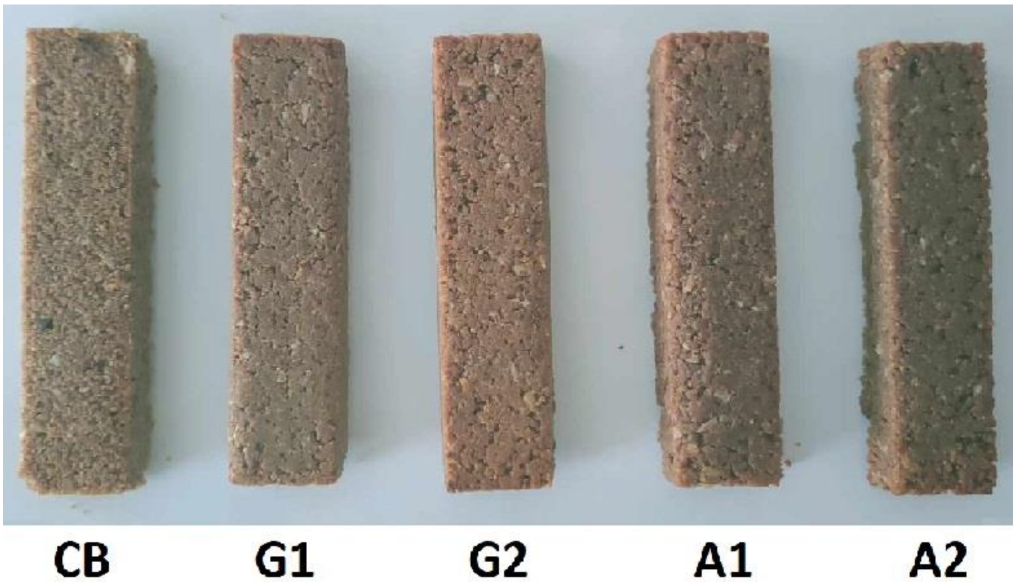

Figure 1. Pictures of the experimental products: CB—control bars; G1—bars with 10 g grape pomace addition; G2—bars with 20 g grape pomace addition; A1—bars with 10 g apple pomace addition; A2—bars with 20 g apple pomace addition.

3.1. Chemical Analysis

The moisture content in the cereal bars from the control sample (Table 2) was at a level typical of this type of product and was approximately 16.3%. The addition of the fruit pomace resulted in a significant increase in the moisture content of the products. The increase in the moisture content of products containing dried/powdered fruit pomace is probably related to the high pectin content. These substances are responsible for the ability of products to retain water [22,23]. Low-moisture bakery products, such as cereal bars and biscuits, are generally characterized by long life due to their low water activity. However, during storage, quality decay occurs due to moisture adsorption or the development of lipid oxidation. Oxidation is a complex set of reactions, which can be prevented by the addition of antioxidants in the formulation [24]. Therefore, moisture control plays a critical role in determining the quality and shelf life of cereal snacks. Additional protective measures are necessary for products with higher water content. Appropriate storage conditions, new aseptic technologies, and controlled atmosphere/modified atmosphere packaging can extend the product shelf life [25].

Table 2. Chemical compositions of cereal bars fortified with grape and apple pomace.

Sample	Moisture [%]	TPC [mg/g]	IDF [%]	SDF [%]	TDF [%]
CB	16.28 ± 0.62^{e}	1.21 ± 0.02^{b}	12.23 ± 0.11^{a}	5.11 ± 0.08^{c}	17.34 ± 0.19^{ab}
G1	18.13 ± 0.07^{d}	1.00 ± 0.03^{a}	11.60 ± 0.07^{b}	5.44 ± 0.06^{b}	17.04 ± 0.13^{b}
G2	19.50 ± 0.36^{c}	1.04 ± 0.05^{a}	10.84 ± 0.11^{c}	5.45 ± 0.04^{b}	16.29 ± 0.15^{c}
A1	21.17 ± 0.37^{b}	1.03 ± 0.01^{a}	12.26 ± 0.12^{a}	5.36 ± 0.04^{b}	17.62 ± 0.17^{a}
A2	23.64 ± 0.23^{a}	0.94 ± 0.05^{a}	11.54 ± 0.05^{b}	5.75 ± 0.07^{a}	17.30 ± 0.11^{ab}

CB—control bars; G1—bars with 10 g grape pomace addition; G2—bars with 20 g grape pomace addition; A1—bars with 10 g apple pomace addition; A2—bars with 20 g apple pomace addition. Data are presented as mean ($n = 3$) ± standard deviation; values of each parameter with different superscript letter in the rows are significantly different (Tukey test $p \leq 0.05$).

The highest average polyphenol content was recorded in the sample of bars with the unmodified recipe. The addition of grape and apple pomace reduced the content of antioxidant compounds. It was further observed that the increase in the proportion of fruit residues from 10 to 20 g had no significant effect on changes in the number of polyphenols in the cereal bars. It should be noted that sultanas, or dried grapes, were substituted with the fruit residue, i.e., raw materials with very high polyphenol content (10.7 mg of GAE/g wet weight) [26]. In studies conducted by other authors, where pomace was used to substitute cereal raw materials, the polyphenol content increased significantly in the fortified products [27–29].

The addition of the apple and grape pomace resulted in a significant increase in soluble dietary fibre (SDF). The relatively high SDF content in the fruit residue-supplemented bars was probably related to the high pectin content, i.e., over 14 g/100 g of dried apple pomace [30]. The average insoluble fibre and total fibre content also increased after the addition of 10 g of the apple residue. However, the statistical analysis did not confirm the significance of these changes. In contrast, it was observed that the introduction of 20 g of the grape residue into the recipe reduced the amount of total dietary fibre (TDF).

3.2. Analysis of Physical Properties

The strength of the cereal bars changed significantly when the fruit pomace was introduced into the recipe (Figure 2). The use of the grape residues had a positive effect on the mechanical properties of the products. The force required to break down the bars increased by almost 20%. In contrast, the addition of the apple pomace resulted in a decrease in the breaking strength of the cereal bars, but the changes were only significant when the proportion of the apple residue was increased from 10 to 20 g per dough portion. The increased strength of the cereal bars may be related to an increase in adhesiveness, i.e., the strength of the internal bonds holding the product together. The parameters described are closely related to the technological properties and composition of the food raw materials. Higher moisture content, water binding capacity, and the presence of structure-forming substances, such as cellulose or pectin, have a positive effect on the compactness of the product, thereby increasing its resistance to pressure damage [31].

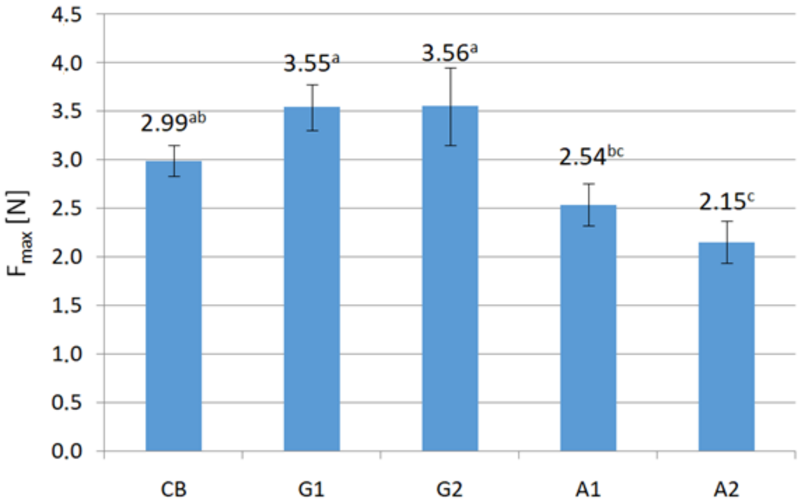

Figure 2. Strength of cereal bars fortified with grape and apple pomace: CB—control bars; G1—bars with 10 g grape pomace addition; G2—bars with 20 g grape pomace addition; A1—bars with 10 g apple pomace addition; A2—bars with 20 g apple pomace addition. Data are presented as mean (n = 5). Error bars indicate standard deviations; values of each parameter with different superscript letters in the rows are significantly different (Tukey test $p \leq 0.05$).

3.3. Colour Parameters

The L^* colour brightness of the cereal bars did not change significantly ($p > 0.05$) after the modification of their recipe (Table 3). The values of the parameter a^* increased slightly after the addition of the tested food by-products, but the statistical analysis showed that these changes were not significant ($p > 0.05$). On the other hand, it was observed that the introduction of the apple pomace had an impact on the mean values of the parameter b^*. This parameter of cereal bars fortified with the apple residues significantly decreased, which indicates that the colour of the A1 and A2 bars was less chromatic towards yellow than that of the CB bars. Regardless of the amount and type of the fruit pomace used, the colour difference $2 < \Delta E < 5$, in comparison with the unmodified product, was noticeable to the panellists [32]. Similar trends in the colour change in cereal bars were observed in an experiment conducted by Sandini et al. (2020) [33]. Likewise in the present study, the authors modified the bar recipe by replacing sultanas with biomass from grape wine fermentation. The colour analysis showed no significant differences in the L^* and a^* parameters. However, the introduction of the by-product was found to result in a reduction in the b^* and C^* parameters. It was therefore concluded that a lower saturation value (C^*) was indicative of a darkening of the sample following the introduction of the winemaking residue.

Table 3. Colour parameters of cereal bars fortified with grape and apple pomace.

Sample	L^*	a^*	b^*	ΔE
CB	33.98 ± 6.57	7.49 ± 2.00	18.61 ± 2.65 ^{a}	
G1	36.10 ± 2.77	8.67 ± 0.57	17.78 ± 1.58 ^{abc}	2.56
G2	37.40 ± 0.82	9.22 ± 0.81	16.28 ± 0.73 ^{ab}	4.48
A1	35.78 ± 0.76	8.20 ± 0.30	15.17 ± 0.75 ^{c}	3.95
A2	36.96 ± 0.65	8.32 ± 0.33	14.82 ± 0.98 ^{bc}	4.89

CB—control bars; G1—bars with 10 g grape pomace addition; G2—bars with 20 g grape pomace addition; A1—bars with 10 g apple pomace addition; A2—bars with 20 g apple pomace addition. Data are presented as mean (n = 5) ± standard deviation; values of each parameter with different superscript letter in the rows are significantly different (Tukey test $p \leq 0.05$). For parameters L^* and a^* $p > 0.05$.

3.4. Sensory Evaluation

The introduction of the grape and apple residues into the recipe of the cereal bars contributed to significant changes in sensory properties. The results of the sensory evaluation are shown in Figure 3. The data obtained demonstrate a positive effect of the addition of the apple pomace on the visual characteristics of the cereal bars. The introduction of the apple and grape residue into the bar recipe resulted in deterioration of the aroma. Probably, the use of a higher dose of the apple and grape residues would have facilitated identification of the aroma by the panelists [34].

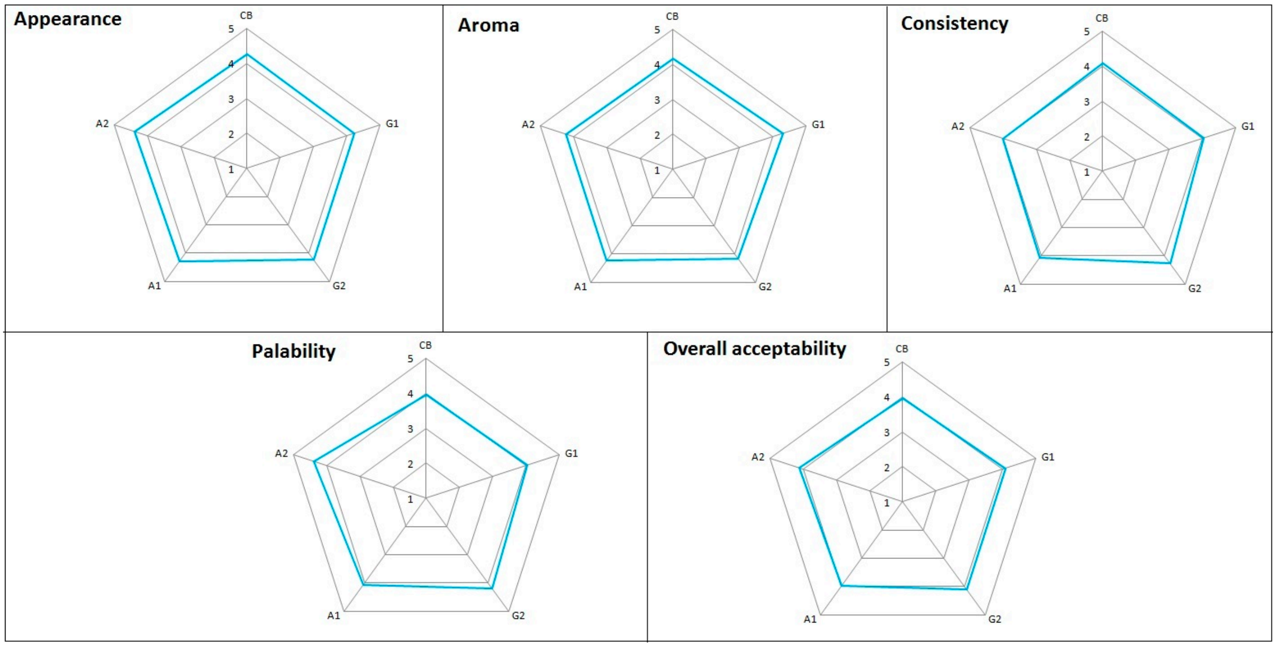

Figure 3. Sensory evaluation of cereal bars fortified with grape and apple pomace: CB—control bars; G1—bars with 10 g grape pomace addition; G2—bars with 20 g grape pomace addition; A1—bars with 10 g apple pomace addition; A2—bars with 20 g apple pomace addition.

The consistency of the bars containing the fruit pomace did change according to the tasters. The use of 20 g of the grape pomace (G2) had a positive effect on the texture of the products. However, the introduction of the same amount of the apple pomace into the recipe resulted in a deterioration of the consistency of the bars. The textural properties of this type of snack are highly dependent on the moisture content and composition of the product. The apple pomace-fortified cereal bars were characterised by higher moisture content. This parameter increased with the increasing proportion of the fruit residue, which probably resulted in a deterioration of the textural properties of the products [35].

The modification of the recipe with 20 g of the fruit pomace resulted in favourable changes in the palatability of the bars but did not affect their flavour. Palatability is a characteristic that largely determines the acceptability of a food product. The introduction of fruit processing by-products into cereal snacks usually does not result in adverse changes in their taste. However, it may have a negative impact on their texture [36,37].

The sugar-free cereal bars containing the fruit pomace were better accepted by the panellists, especially those supplemented with a higher amount of the by-products.

4. Conclusions

The results of the experiment show that cereal bars can be enriched with waste products from the fruit industry. Products fortified with grape and apple pomace have partially different properties than traditional cereal bars. The introduction of fruit residues increases product moisture and soluble dietary fibre content. These changes probably contribute to an increase in the mechanical strength of the bars, with concomitant deterioration in texture assessed sensorially (in products fortified with 20 g of apple pomace). As shown in the study, the introduction of fruit residues does not affect the palatability of the product. However, the colour of the cereal bars changes. It is presumed that consumers will notice a colour difference compared to the unmodified product ($2 < \Delta E < 5$), while the results of the sensory evaluation show a positive effect of the addition of fruit pomace on the visual characteristics of the cereal bars.

In conclusion, cereal bars are products with great potential for sustainable food production, contributing to the generation of as little waste as possible. Cereal bars containing grape pomace and up to 10 g of apple pomace are characterised by high soluble dietary fibre content and desirable sensory and mechanical properties. Therefore, they are recommended for industrial production. Importantly, these fortified products are characterised by high moisture content. In further studies, it will be necessary to evaluate the quality of the product during storage to determine the shelf life and appropriate storage temperature. It is also recommended to conduct further research on the colour change in fortified products stored for a longer time.

Low mechanical strength and very high moisture content of bars containing 20 g of apple pomace may have a disadvantageous effect on the shelf life and preservation of the structure of the products during transport and storage. Therefore, it is not recommended to use bars made according to recipe A2 for industrial production.

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