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SUSTAINABLE APPLICATIONS OF CEREAL-BASED PRODUCTS THROUGH THE UTILISATION OF FRUIT WASTE

S u m m a r y

Background. The fruit and vegetable processing industry plays a key role in the agri-food industry. Nowadays, the huge quantities of fruit and waste disposed have attracted the attention of several sectors worldwide, not only because of the concern over environmental impacts but also because of the high proportions of nutrients and bioactive compounds these inedible parts can provide. This study explores the valorization of fruit waste through the incorporation of banana and mandarin peel powder (PP) into cereal-based products as an approach to support sustainability and healthy diet. Banana and mandarin peels were processed into a powder form and added to muffins and cookies at concentrations of 3 %, 5 % and 8 %. The samples were analyzed on the day of preparation as well as after 1, 2, 3 and 5 days of storage.

Results and conclusions. Comprehensive physico-chemical analyses demonstrated improvements in nutritional and functional properties compared to control samples. Specifically, the addition of peel powder resulted in elevated energy values, enhanced the nutritional quality by increasing the protein content (up to 12.8 %), total fat (up to 7.84 %), total carbohydrates (up to 11.4 %), total ash (up to 76.9 %), and total vitamin C content (up to 3.95-fold). Furthermore, fruit peel powder acted as a moisture binder agent, by reducing the moisture content and water activity potentially extending product shelf life. Mandarin peel powder exerted a more pronounced effect on physico-chemical characteristics compared to banana peel powder. Additionally, the incorporation of fruit peel powder substantially elevated the levels of total polyphenols, flavonoids and antioxidant activity, with values up to 2.7-fold higher than the control samples. Sensory evaluations confirmed the acceptability of the products, with overall quality ratings ranging from 6.6 to 8.2 on a 9-point hedonic scale. This research underscores the viability of fruit peel powder as a sustainable ingredient for reducing food waste, while enhancing the nutritional profile and functionality of cereal-based products.

Keywords: fruit waste utilization, peel powder, cereal-based products, nutritional enhancement, sustainability, antioxidant activity

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Introduction

Bananas (*Musa paradaisica L.*) and mandarins (*Citrus reticulata*) constitute the types of fruit which are widely cultivated in tropical and subtropical regions across the globe. Both of these fruit types offer numerous benefits in terms of improving diet quality and can be consumed fresh, processed into various products or used as ingredients in functional foods [2]. Moreover, their industrial processing ensures the efficient utilization of raw materials and minimizes food losses [3].

One significant aspect of both these fruit types is their peel, which accounts for more than 30 % of the total fruit mass [6]. Unfortunately, this results in the generation of several tons of organic waste annually, most of which ends up in landfills or marine environments along with general waste [7]. Consequently, the food-processing industry faces a major challenge in reducing and managing such vast quantities of waste. This concern stems from the need to minimize negative environmental impacts and achieve sustainable development outcomes [10]. To address this issue, it is crucial to develop innovative strategies for the valorization of fruit waste [12].

Citrus and banana peels have been found to contain significant amounts of fiber, pectin, vitamin C, polyphenols and other valuable compounds. This composition renders them highly suitable for exploitation as value-added food products [13]. Consequently, the objective of this paper is to explore the potential of utilizing mandarin and banana peel waste in muffins and cookies as an approach to sustainability [14]. By incorporating fruit peel waste into baked goods, we can not only address the waste management challenge but also enhance the nutritional value of the final products. This approach aligns with the principles of the circular economy, where waste is minimized, resources are maximized, and environmental sustainability is prioritized [15].

The inclusion of mandarin and banana peels in muffins and cookies offers several advantages. Firstly, it significantly boosts the fiber content of these baked goods [16]. Fruit peels are rich in dietary fiber, and increased fiber intake has been associated with numerous health benefits, including improved digestion, reduced risk of chronic diseases and weight management [18]. Incorporating fruit peels can help individuals meet their daily fiber requirements in a delicious and convenient manner. Secondly, the peels are a valuable source of pectin, a natural polysaccharide widely used as a gelling agent in the food industry [19]. By adding pectin derived from fruit peels, we can enhance the texture and moisture retention of muffins and cookies, resulting in improved quality and prolonged shelf life [20].

Moreover, the peels contain significant amounts of vitamin C and polyphenols, which serve as potent antioxidants [21]. Antioxidants play a vital role in neutralizing harmful free radicals in the body, thereby protecting against oxidative stress and reducing the risk of chronic diseases [26]. The incorporation of mandarin and banana peels into baked goods can elevate their antioxidant content, providing consumers with an enjoyable way to increase their antioxidant intake [25].

In addition to the nutritional benefits, the utilization of fruit peels in muffins and cookies can impart unique flavors and aromas [27]. The peels contribute a delightful citrusy note to the baked goods, enhancing their taste and sensory appeal. This flavor infusion can be particularly appealing to individuals who appreciate citrus flavors or seek novel taste experiences [28].

The aim of this research is to explore the potential of utilizing banana and mandarin peel waste in muffins and cookies as a sustainable approach. By incorporating banana and mandarin peel powder into baked goods, the study aims to address the challenge of waste management, while also enhancing the nutritional and functional qualities of the finished products. The research seeks to demonstrate that the inclusion of peel powder leads to improvements in various aspects of cereal-based products (muffins and cookies). This includes increasing the energy value, protein content, total fat, total carbohydrates, total ash, vitamin C content, total bioactive compounds and antioxidant activity compared to control samples. Additionally, the sensory attributes of the final products, namely appearance, taste, aroma, texture and overall quality, will be evaluated.

Material and methods

Preparation of banana and mandarin peel powder and cereal-based products

Preparation of banana and mandarin peel powder

In this study, banana (*Musa paradaisica* L.) and mandarin (*Citrus reticulata*) fruit was procured from the local market in Tirana (Albania). Prior to processing, both fruit types underwent a thorough washing process with distilled water to ensure cleanliness. Afterward, only the peel (weighing at least 3 kg wet) was utilized and further cut into small pieces and subjected to sun-drying until the moisture content reached 5 %. Once adequately dried, the fruit peel was transformed into a powder form using a blender and then sieved to obtain a fine peel powder (PP).

Preparation of cereal-based products

For muffins and cookies, traditional recipes (Table 1) were applied, dough was prepared by mixing thoroughly all ingredients till a homogeneous dough was taken, while peel powder of banana (PPB) and peel powder of mandarin (PPM) were gradually incorporated into the dough and finally, the baking powder was added. The various ingredients used in this study (white wheat flour, brown sugar, salt, baking powder, olive oil, eggs, milk and yogurt) were acquired from the domestic market in Tirana, Albania. The control samples of muffins (M) and cookies (C) were prepared without the addition of PP of banana (PPB) and mandarin (PPM), using only white wheat flour. Additionally, different formulations were created by substituting wheat flour in various proportions with PPB and PPM, respectively these formulations included 3 % of the mixture (M_PPB3 and C_PPB3, M_PPM3 and C_PPM3), 5 % (M_PPB5 and C_PPB5, M_PPM5 and C_PPM5), and 8 % (M_PPB8 and C_PPB8, M_PPM8 and C_PPM8), as a substitute for wheat flour. The muffins were poured in equal portions of 30 g in small pans, while for cookies, the dough was rolled into a sheet of uniform thickness, cut into round shape pieces, and then placed in an oven at 180 ÷ 200 ^{o}C for 10 ÷ 12 min.

Table 1. The codes of study samples
Tabela 1. Kody badanych próbek

Muffin control / Muffina kontrolna (M)*	Peel powder / Sproszkowane skórki (PP)**	Muffin with mandarin peel powder / Muffiny ze sproszkowana skórką z mandarynek (M_PPM)	Muffin with banana peel powder / Muffiny ze sproszkowana skórką z bananów (M_PPB)
white wheat flour / biała mąka pszenna (34.3 %), brown sugar / cukier brązowy (21.4 %), salt / sól (0.5 %), baking powder / proszek do pieczenia (1.5 %), olive oil / oliwa (10.1 %), eggs / jaja (10 %) milk / mleko (22.2 %)	3 %	M_PPM3	M_PPB3
	5 %	M_PPM5	M_PPB5
	8 %	M_PPM8	M_PPB8
Cookies control /Ciastko kontrolne (C)*	Peel powder / Sproszkowane skórki (PP)	Cookies with mandarin peel powder / Ciastka ze sproszkowaną skórką z mandarynek (M_MPP)	Cookies with banana peel powder / Ciastka ze sproszkowana skórką z bananów (M_BPP)
white wheat flour / biała mąka pszenna (47.6 %), brown sugar / cukier brązowy (14.3 %), salt / sól (0.4 %), baking powder / proszek do pieczenia (1.3 %), olive oil / oliwa (7.5 %), eggs / jaja (9.2 %) yogurt / jogurt (19.7 %)	3 %	C_PPM3	C_PPB3
	5 %	C_PPM5	C_PPB5
	8 %	C_PPM8	C_PPB8

Explanatory notes / Objaśnienia:
*The proportions of components were expressed as fractions (%) of the mixture, with the sum of proportions equal to 100 %; **The fruit peel powder was applied as a flour substitute in muffins and cookies in the total mass prepared / *Proporcje składników wyrażono jako ułamki (%) mieszaniny, przy czym suma proporcji wynosi 100 %; **Proszek ze skórek owoców zastosowano jako zamiennik mąki w muffinkach i ciasteczkach w całej przygotowanej masie.

Once cooled, each sample was individually packaged in commercial multi-layer film bags using a partial vacuum sealing technique. This packaging method helped to maintain the quality and freshness of the baked goods until all subsequent analyses were conducted. The muffins and cookies were prepared in triplicate.

Throughout the study, only chemicals of analytical grade were utilized. These high-quality chemicals ensure the accuracy and reliability of the analytical procedures employed in the experiments. The use of analytical-grade chemicals is important in research settings as it helps to minimize potential contaminants and inconsistencies that may affect the results and interpretation of the study.

Overall, this study involved the procurement, processing and utilization of banana and mandarin fruit peel in the form of a powdery ingredient for the preparation of muffins and cookies. The control samples without PP were compared to different formulations containing 3, 5 and 8 % of PP. By analyzing and comparing the sensory, nutritional and other relevant properties of the baked goods, the researchers aimed to evaluate the effects of incorporating PP into the recipes. The careful selection of ingredients, the use of analytical-grade chemicals and the appropriate packaging techniques contribute to ensuring the accuracy and validity of the experimental results obtained in this study.

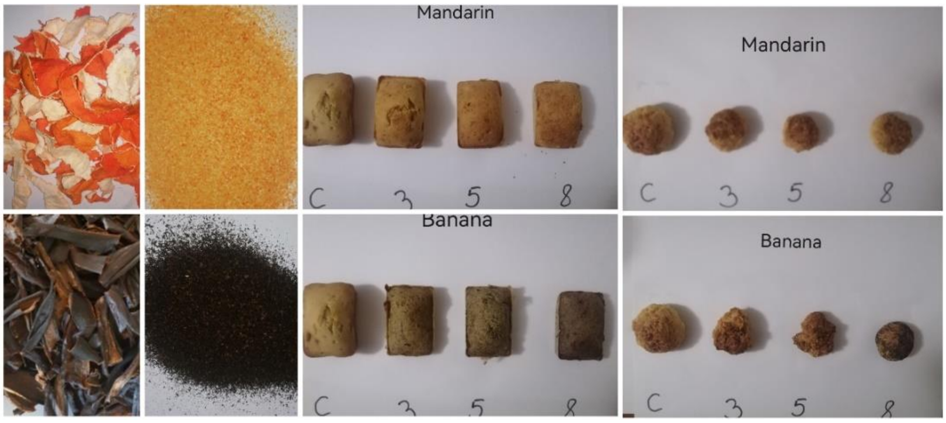

Figure 1. Study samples: mandarin and banana peels, dried and powdered (PP), muffins and cookies enriched with PP in different formulations (3, 5 and 8 %)

Rycina 1. Próbki do badań: skórki mandarynek i bananów, suszone i sproszkowane (PP), babeczki i ciasteczka wzbogacone PP w różnych recepturach (3, 5 i 8 %)

Analytical methods

Evaluation of physico-chemical properties of the cereal-based products

To assess the nutritional composition and other relevant properties of the samples, several analyses were conducted using the methods outlined by the Association of Official Analytical Chemists (AOAC) [1]. The total content of protein, fat, ash, total acidity (TA) and vitamin C was determined for each sample. These analyses provide valuable information about the macronutrient composition and the acidity level of the samples, as well as the presence of vitamin C, an important nutrient. The results obtained from these analyses were expressed as grams per 100 grams of fresh weight (FW) of the sample, allowing for easy comparison between the different formulations.

Energy content

To calculate the energy values of the samples, the Atwater factor was applied. The Atwater factor is a widely used method for estimating the caloric content of food based on the energy contribution of each macronutrient. In this study, a factor of 4 kcal per gram was used for both protein and carbohydrates, while a factor of 9 kcal per gram was used for fat. By applying these factors to the respective amounts of protein, fat and carbohydrates in the samples, the energy values were calculated.

Moisture measurement

Moisture content was determined using an advanced moisture analyzer Ohaus, where 0.5 ± 0.002 g of the sample was uniformly distributed on an aluminum plate. The results were expressed in g/100 g (wet basis) and performed in triplicate.

Determination of protein

Protein was determined using the Kjeldahl method according to AOAC (ref. 976.05) [1], Kjeldahl system Foss™ (Thermo Fisher Scientific Inc., Waltham, MA USA) was used for nitrogen and protein analysis, after distillation and titration, the nitrogen was multiplied by a 5.7 factor. The results were expressed in g/100 g (wet basis) and performed in triplicate.

Determination of total fat

Total fat was determined by the Soxhlet (Behrotest, Labor-Technik GmbH, Düsseldorf, Germany) standard extraction method with ethyl ether, according to AOAC (ref. 963.15) [1]. The results were expressed in g/100 g (wet basis) and analyzed in triplicate.

Determination of total ash

Total ash was determined gravimetrically, after incineration in a muffle furnace (Heraeus M104, Thermo Fisher Scientific, USA), at 600 °C. The results were expressed in g/100 g (wet basis). Total ash was analyzed in triplicate.

Determination of carbohydrates

The carbohydrate content was determined by difference [100 - (protein + fat + ash + water)]. Since the total content of protein, fat, ash and water was known, the remaining percentage was attributed to carbohydrates. This calculation method accounts for all the major macronutrients present in the samples and ensures that the values add up to 100 %. All measurements were performed in triplicate.

pH and total acidity measurement

The measurement of pH was performed with a Benchtop pH meter (Ultra Basic Model UB-10, Denver Instrument, USA), having an accuracy of 0.001 pH, and previously calibrated with 4.00 and 7.00 pH buffer solutions. The total acidity was determined by titration with sodium hydroxide solution 0.1 M according to AOAC ref. 942.15, and ref. 920.14 [1], and the results were expressed as % citric acid. The pH and total acidity were determined in triplicate.

Water activity measurement

The water activity (aw) of the samples was measured at a temperature of 25 °C using a water activity meter, specifically the Retronic model. To ensure accurate readings, the water activity meter was calibrated with appropriate standards, such as those with the known water activity of 1.000 a_w. The measurement of water activity provides information about the water availability and stability of the samples, which can influence their shelf life and microbial growth. The measurement of water activity was performed in triplicate.

Color measurement

The color value of the samples was determined using a portable colorimeter called NH310. This device measures color based on the CIE (Commission Internationale de l'Eclairage) parameters *L**, *a**, and *b**. The *L** parameter represents lightness, ranging from 0 (black) to 100 (white). The *a** parameter measures the greenness (-) to redness (+) spectrum, while the *b** parameter measures the blueness (-) to yellowness (+) spectrum. By quantifying these color parameters, the colorimeter provides objective data on the appearance and visual characteristics of the samples. The color *L**, *a** and *b** were measured in triplicate.

Determination of vitamin C

Vitamin C was determined according to Mussa and El Sharaa [17], an amount of 20 cm^3 of the sample solution in a 250 cm^3 beaker was added to about 150 cm^3 of distilled water and 1 mL of 1 % starch indicator solution. The solution was titrated with 0.005 M I_2 standard solution, and the end point of the titration was identified by the first trace of dark blue color (due to the starch-iodine complex). The titration was repeated with other samples, until we obtained compatible results (difference in titters < 0.1 cm^3), and a mean volume was calculated for the iodine solution used and then the moles of ascorbic acid reacting with iodine that react were calculated. The concentrations were calculated in mg of ascorbic acid/100 g sample FW (fresh weight). All measurements were performed in triplicate.

By conducting these analyses, the researchers aimed to gather comprehensive information about the nutritional composition, water activity and color properties of the samples. This data contributes to the overall understanding of the samples' quality, nutritional value and potential sensory attributes. The application of standardized methods, calibration of instruments and adherence to recognized analytical protocols ensure the accuracy and reliability of the obtained results.

Determination of bioactive compounds and antioxidant activity of baked goods

Extracts preparation

To extract bioactive compounds from the samples, a specific extraction procedure was followed. A precise amount of 0.5 ± 0.002 g of sample was mixed with 10 cm^3 of acidified methanol, which contained 80 % methanol and 1 % hydrochloric acid (HCl). The mixture was then vigorously vortexed for 5 minutes to ensure thorough extraction. Subsequently, centrifugation was carried out at a temperature of 20 °C, at a speed of 4,500 revolutions per minute (rpm) for 15 minutes. This process allowed for the separation of the supernatant, which was collected for further analysis. The collected supernatant was then filtered to remove any particulate matter. This entire extraction procedure was performed in triplicate to ensure accuracy and reproducibility.

Determination of total polyphenols

The total polyphenols in the samples were determined using the Folin-Ciocalteu method according to Singleton and Rossi [22] and Hoxha and Kongoli [9]. Folin-Ciocalteu (Fluka) reagent (diluted five times) was mixed with 0.2 cm^3 of extracts and 0.5 cm^3 7.5 % Na_2CO_3. The reaction took 30 minutes at room temperature in darkness. In this method, after reaction time, the absorption of the samples was measured against a blank using a UV-Vis spectrophotometer (Libra S22, Bichrom UK) at a wavelength of 765 nm. The absorbance readings were taken in triplicate. The results obtained from the spectrophotometric measurements were expressed as milligrams of gallic acid equivalents (GAE) per 100 grams of fresh weight (FW) of the sample, according to a calibration curve, built in the range of 0.02 ÷ 0.10 mg gallic acid (Fluka) standard. This measurement provides information about the total content of polyphenolic compounds in the samples. The total polyphenols were determined in triplicate.

Determination of total flavonoids

Total flavonoids content was determined colorimetrically by the method described previously by Hoxha and Kongoli [9] and Zubair et al. [29]. Each obtained extract (1 mL) was placed in10 cm^3 volumetric flasks, then distilled water in the amount of 5 cm^3 and 0.3 cm^3 of 5 % $NaNO_2$ (Merck) was added, and after 5 minutes 0.3 cm^3 of 10 % $AlCl_3$ (Merck, Germany) was added. After another 6 minutes, 2 cm^3 of 1 M NaOH (Merck) was added and made up to the volume of 10 cm^3 with distilled water. The reaction mixture absorbance was measured at 510 nm using a UV-Vis spectrophotometer (Bichrom, UK). The results were expressed in mg equivalent of (+) catechin per 100 g FW, according to the calibration curve, linear in the range of 10 ÷ 100 μg/ cm^3 (+) catechin (Sigma, Germany) standard. The total flavonoids were determined in triplicate.

Determination of antioxidant activity

The antioxidant activity was assessed by two tests: ABTS (2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) and DPPH (2,2-diphenyl-1-picrylhydrazyl).

ABTS radical scavenging assay

The antioxidant activity of the extracts was determined by ABTS radical scavenging assay [9]. The ABTS (2,2-azinobis-3-ethylbenzothiazoline-6-sulfonic acid) radical cation was generated by mixing 7.0 mM ABTS (Sigma, Germany) in dd H_2O and 2.45 mM potassium persulfate (Merck, Germany) in dd H_2O, and the reaction was performed for 16 hours at room temperature in darkness before use. The stock solution was diluted in methanol (VVR) until the absorption at 734 nm was 0.7± 0.02. For the assay, 985 μl of $ABTS^+$ solution was mixed with 15 μl of the extract. The absorption of the sample was measured after 6 minutes of reagent addition using spectrophotometer (Bichrom, UK). The antioxidant activity of the extract was expressed as mg ascorbic acid equivalent (AAE) per 100 g of sample in FW basis. This test was conducted in triplicate.

DPPH radical scavenging assay

DPPH radical scavenging activity of fig extracts was performed employing the methods of Sun et al. [23] with some modifications. The sample extracts of 30 μl were completed to 2 cm^3 with 0.1 mM DPPH (Sigma, Germany). The mixture was vortexed for 20 seconds. The absorbance was measured at 515 nm using a spectrophotometer

(Libra S22, Bichrom, UK), after 20 minutes incubation at room temperature and in darkness. As a blank solution, 2 cm^3 of 80 % methanol was used. The absorbance of DPPH (2 cm^3) was $A_{control}$. The inhibition percentage of the absorbance was calculated as follows: Inhibition % = $(A_{control} – A_{sample})/A_{control}$. The DPPH test was performed in triplicate.

All the measurements for polyphenols, flavonoids and antioxidant activity were performed in triplicate, ensuring reliable and reproducible results. By conducting these analyses, the researchers aimed to assess the presence of bioactive compounds and the antioxidant potential of the samples. This information contributes to understanding the potential health benefits and functional properties of the samples, making them valuable for further applications in food and nutrition.

Evaluation of sensorial characteristics

To assess the sensory attributes of the samples, a panel of 10 non-trained participants was recruited. The panelists were asked to evaluate the appearance, flavor, aroma, gumminess, texture and the overall quality of the samples using a 9-point hedonic scale. This scale allowed the panelists to rate their preference or liking for each sensory characteristic on a scale ranging from 1 to 9.

The 9-point hedonic scale used in the evaluation was as follows: 1 - dislike extremely, 2 - dislike very much, 3 - dislike moderately, 4 - dislike slightly, 5 - neither like nor dislike, 6 - like slightly, 7 - like moderately, 8 - like very much, and 9 - like extremely. This scale provided a range of options for the panelists to express their level of liking or disliking for each attribute. Each panelist evaluated the samples independently and provided their ratings for appearance, flavor, aroma, gumminess, texture and overall quality. This allowed for multiple individual opinions to be gathered, providing a comprehensive assessment of the sensory characteristics.

The use of non-trained participants in the sensory evaluation ensures the representation of the general consumer population, as they do not possess specialized training that could bias their judgments. This approach allows for a more realistic reflection of how the samples would be perceived by consumers in terms of their sensory attributes.

By employing this evaluation method, the researchers aimed to gain insights into the acceptability and the overall sensory appeal of the samples. The panelists’ ratings provided valuable information regarding the samples' appearance, taste, aroma, texture, and overall desirability. This sensory evaluation complements the chemical and nutritional analyses, providing a holistic understanding of the samples' quality and consumer acceptance.

Statistical Analysis

To assess the stability and changes in the samples over time, all measurements were conducted in triplicate and at different time points: at the time of preparation, as well as after 1 day, 2 days, 3 days and 5 days of storage. This allowed for the evaluation of the effect of the peel powder (PP) on the muffins and cookies during the storage. Descriptive statistics were produced using the Statistical Package for the Social Sciences (SPSS) (IBM Version 28.0, Armonk, NY). The results obtained were analyzed and reported as mean values, representing the average of the measurements, along with the corresponding standard deviation (SD), which indicates the degree of variability within the triplicate measurements. This reporting method allows for the representation of both the central tendency and the level of dispersion in the data, providing a comprehensive understanding of the results obtained. By conducting measurements in triplicate and analyzing mean values with standard deviation, the researchers ensure the reliability and accuracy of the reported results. This approach also helps to account for any natural variation that may occur between individual samples and provides robust representation of the overall trends and changes observed during the storage period.

Results and discussion

Physico-chemical characteristics of the cereal-based products

The nutritional values of muffins and cookies enriched with mandarin and banana peel powder were evaluated and the results are presented in Table 1 and Figures 2 ÷ 4. The energy value of the muffins and cookies ranged from 1,384 to 1,709 kJ/100 g FW of sample. When compared to the control samples, the products enriched with peel powder exhibited higher energy values, with an increase of up to 10.3 %. This indicates that the addition of mandarin and banana peel powder contributes to the overall caloric content of the products.

The total protein content in the muffins and cookies ranged from 4.7 to 5.5 g/100 g FW of sample, with a standard deviation (SD) of 0.22. The incorporation of peel powder led to an increase in protein content of up to 12.8 % compared to the control samples. This suggests that peel powder is a good source of protein, which enhances the nutritional profile of products.

The total fat content in the muffins and cookies varied from 10.2 to 11.1 g/100 g FW of the sample, with an SD of 0.23. The addition of peel powder resulted in a fat content increase of up to 7.84 % compared to the control samples. This indicates that the peel powder contributed to the overall fat content of the products. The total carbohydrate content in the muffins and cookies ranged from 56.2 to 73.2 g/100 g FW of the

Table 1. The nutritional composition of muffins and cookies (control samples and with PP added in different formulations), the results are expressed per 100 g of edible portion

Tabela 1. Skład odżywczy babeczek i ciastek (próbki kontrolne oraz z dodatkiem PP w różnych recepturach), wyniki podano w przeliczeniu na 100 g porcji jadalnej

Sample / Próbka	Energy / Energia [kJ]	Protein / Białko [g]	Fat / Tłuszcz [g]	Carbohydrates / Węglowodany [g]	Ash / Popiół [g]	Vitamin C / Witamina C [mg]
M	1562	4.7±0.02	10.7±0.09	65.7±0.11	0.65±0.2	8.4±0.21
M_PPM3	1580	5.0±0.02	10.9±0.14	66.1±0.19	0.71±0.36	23.2±0.8
M_PPM5	1708	5.2±0.08	11.0±0.01	73.2±0.1	0.78±0.02	32.7±0.02
M_PPM8	1709	5.3±0.03	11.1±0.0	73.0±0.2	1.16±0.04	33.1±0.2
M_PPB3	1579	5.1±0.3	10.8±0.3	66.1±0.3	0.71±0.01	8.7±0.01
M_PPB5	1704	5.2±0.01	10.9±0.01	73.2±0.05	0.78±0.8	16.6±0.01
M_PPB8	1704	5.3±0.04	11.0±0.05	73.0±0.11	1.15±0.01	17.1±0.04
C	1384	4.9±0.05	10.2±0.19	56.2±0.09	0.75±0.11	8.3±0.4
C_PPM3	1450	5.2±0.3	10.8±0.36	58.4±0.8	0.85±0.03	16.5±0.36
C_PPM5	1516	5.3±0.21	10.9±0.05	62.1±0.21	0.93±0.01	23.6±0.3
C_PPM8	1527	5.5±0.8	11.0±0.04	62.3±0.03	0.96±0.05	25.7±0.11
C_PPB3	1425	5.3±0.3	10.8±0.36	56.9±0.8	0.96±0.03	8.5±0.36
C_PPB5	1448	5.4±0.21	10.9±0.05	57.9±0.21	1.06±0.01	15.3±0.3
C_PPB8	1473	5.5±0.8	11.0±0.04	59.2±0.03	1.16±0.05	16.1±0.11

sample. The addition of peel powder increased the carbohydrate content by up to 11.4 % compared to the control samples. This demonstrates that the peel powder added to the carbohydrate content of the products.

The total ash content in the muffins and cookies varied from 0.65 to 1.16 g/100 g FW of the sample. Supplementation with the mandarin and banana peel powder resulted in an increased ash content of up to 76.9 % compared to the control samples. This indicates that the peel powder contributed significantly to the mineral content of the cereal-based products. The total vitamin C content ranged from 8.3 to 33.1 mg/100 g FW of the sample. The addition of fruit peel powder led to higher vitamin C values, with increases of up to 3.95-fold compared to the control samples. This highlights the potential of peel powder as a source of vitamin C, which is an important antioxidant nutrient.

Considering the nutritional values of the muffins and cookies, as well as their corresponding samples enriched with 3 %, 5 % and 8 % mandarin and banana peel powder, it is evident that the utilization of fruit peel powder could be nutritionally advantageous. The peel powder contributed to increased protein, fat, carbohydrate, ash, and vitamin C contents in the products, enhancing their overall nutritional profile.

In a study by Brigagão et al. [4], the optimization of gluten-free muffins using pineapple peel, banana peel and pumpkin seed flours showed that the muffins with pumpkin seed flour increased the lipid content, resulting in reduced firmness. While in the study of Giri et al. [8], it was shown that with the addition of pomegranate peel powder in muffins, the nutritional value was improved by a significant increase in the content of calcium, potassium, magnesium and other nutrient components. This indicates that different types of fruit and seed flours can be used to modify the texture and nutritional composition of baked goods. Furthermore, the previous research also emphasized the positive effects of fruit peels on food products. Citrus and banana peels have been found to increase fiber, pectin, vitamin C and other valuable compounds in food [13, 19, 21]. Pectin derived from fruit peels can enhance the texture and moisture retention of muffins and cookies, improving quality and prolonging shelf life [20]. These findings suggest that the incorporation of fruit peel powder into baked goods offers a promising avenue for enhancing their nutritional value, texture and shelf life. These findings underscore the importance of exploring innovative ways to utilize fruit by-products in food production, contributing to both nutritional enrichment and waste reduction efforts.

Furthermore, Figure 2 illustrates the moisture content of the muffins and cookies both at the onset of production (day 0) and after the storage periods ranging from 1 to 5 days. The moisture content of the muffins and cookies ranged from 11.5 (C_PPB8) to 28.2 (M) g/100 g FW of the sample, with a standard deviation (SD) of 4.2. During the storage period of 1 to 5 days, there was a moisture loss of up to 1.86-fold for the muffins, while the cookies lost moisture up to 1.33-fold. The addition of mandarin peel powder to the muffins resulted in a decrease in moisture content by 2.29-fold compared to the control (M). Similarly, the addition of banana peel powder led to a moisture content decrease of 2.45-fold in the muffins compared to the control. In the case of the cookies, the addition of mandarin and banana peel powder resulted in moisture content decreases of up to 1.53-fold and 1.56-fold, respectively. Notably, banana peel powder demonstrated a superior ability to reduce moisture compared to mandarin peel powder in both muffins and cookies. Contrastingly, Brigagão et al. [4] investigated the optimization of gluten-free muffins using pineapple peel, banana peel and pumpkin seed flours. Their findings revealed that muffins containing pineapple peel flour and banana peel flour exhibited higher moisture content. Additionally, the inclusion of pumpkin

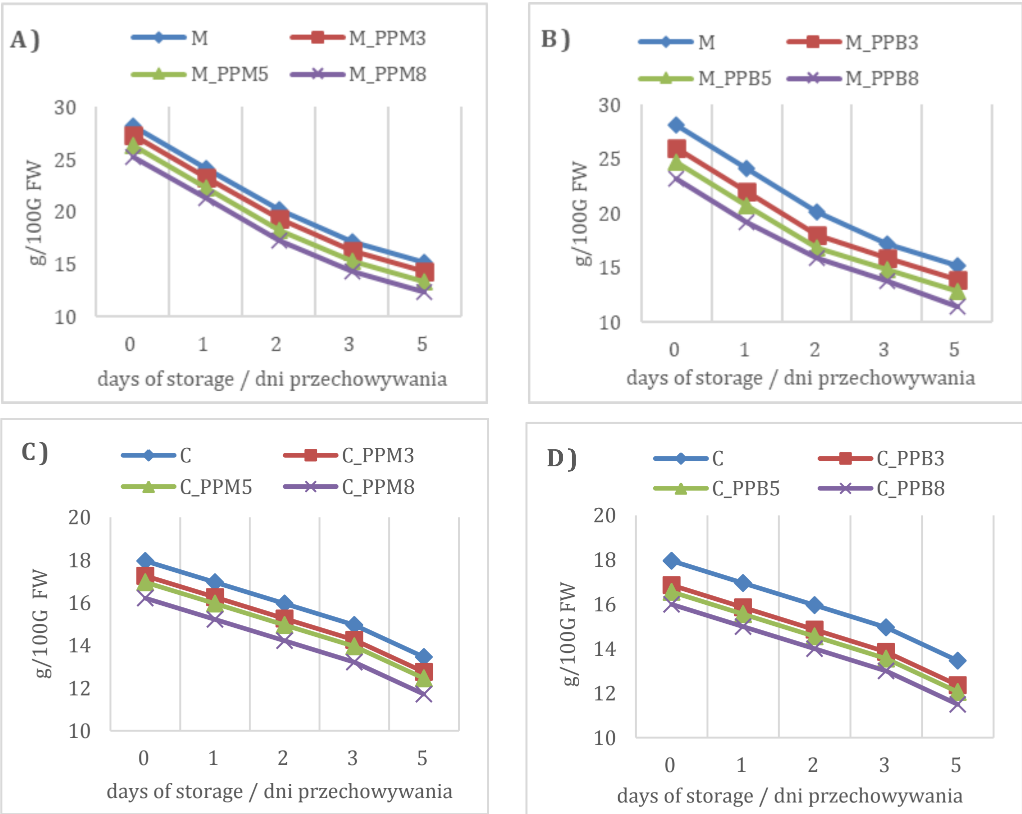

Figure 2. Moisture content of muffins and cookies at the time of production (day 0) and after 1÷5 days of storage a) muffins with mandarin, b) muffins with banana, c) cookies with mandarin and d) cookies with banana

Rycina 2. Wilgotność muffin i ciastek w momencie produkcji (dzień 0) i po 1÷5 dniach przechowywania a) babeczki z mandarynką, b) babeczki z bananem, c) ciasteczka z mandarynką, d) ciasteczka z bananem seed flour increased lipid content and resulted in the reduced firmness of the muffins. These differing outcomes could be attributed to variations in experimental conditions, ingredient formulations and processing techniques employed in the respective studies.

Figure 3 illustrates the water activity (a_w) in the muffins and cookies at two time points: day 0 (production) and after 1 ÷ 5 days of storage. This chart highlights the temporal changes in water activity for these baked goods, crucial for understanding their shelf life and microbial stability. Water activity (a_w) is a vital parameter in food science, indicating water available for microbial growth and chemical reactions.

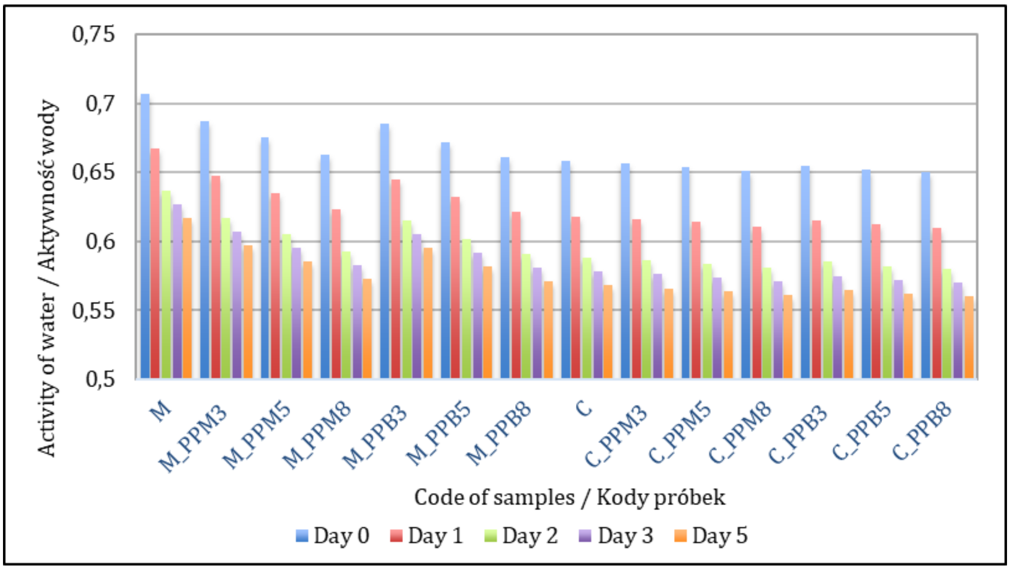

Figure 3. Activity of water (aw) of muffins and cookies at the time of production (day 0) and after 1÷5 days of storage

Rycina 3. Aktywność wody (aw) babeczek i ciasteczek w momencie produkcji (dzień 0) i po 1÷5 dniach przechowywania

The water activity measurements revealed that the control samples had higher aw values: 0.707 for muffins (M) and 0.658 for cookies (C), with a standard deviation of 0.04. In the context of muffins (M) and cookies (C) with varying percentages of fruit peel powder (3 %, 5 % and 8 %), the lowest observed aw value for muffins was 0.571 (M_PPB8, Day 5); conversely, for cookies, the minimum aw value was 0.561 (C_PPM8 and C_PPB8, Day 5) respectively. Incorporating fruit peel powder resulted in lower aw values. During the storage, there was a notable decrease in a_w of up to 26 %. Considering both moisture content and water activity, the addition of fruit peel powder appears beneficial. The powder has water-binding capacity, leading to reduced water content and activity. This variability could enhance product stability and deter microbial growth, potentially extending shelf life. However, further investigation is necessary to validate these findings and comprehend peel powder's impact on product stability and microbial development.

Also, the study examined titratable acidity variations in M (muffins) and C (cookies) with different concentrations of peel powder in all samples (PPM3, PPM5, PPM8, PPB3, PPB5 and PPB8), which are presented in Figure 4. Results showed fluctuating titratable acidity levels in both M and C, ranging from 0.07g citric acid/100 g (M_PPM3) to 0.39g citric acid/100 g (M_PPM8) for M and 0.02g citric acid/100 g (C_PPB3) to 0.24g citric acid/100 g (C_PPM8) for C. Banana peel powder resulted in lower acidity values in both muffins and cookies compared to mandarin peel powder and their respective products.

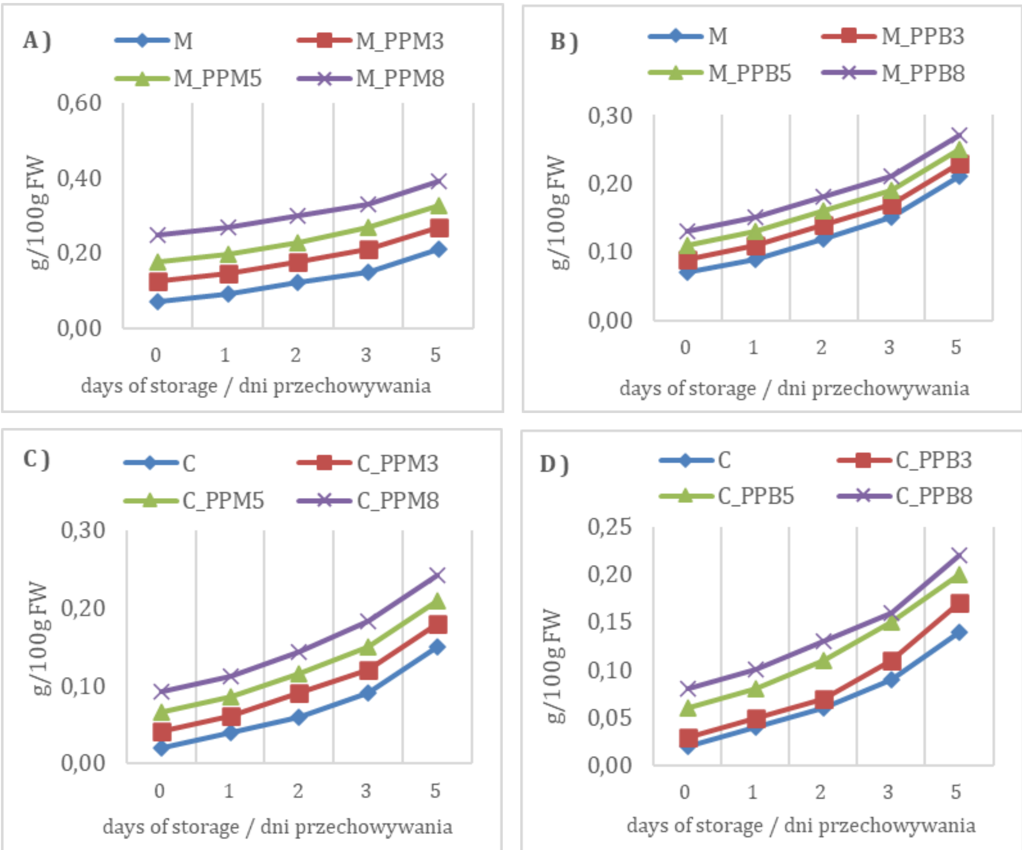

Figure 4. Total acidity of muffin and cookie samples and changes during storage (1÷5 days of storage) A) muffins with mandarin, B) muffins with banana, C) cookies with mandarin and D) cookies with banana

Rycina 4. Kwasowość całkowita próbek babeczek i ciastek oraz zmiany w czasie przechowywania (1÷5 dni przechowywania) A) babeczki z mandarynką, B) babeczki z bananem, C) ciasteczka z mandarynką i D) ciasteczka z bananem

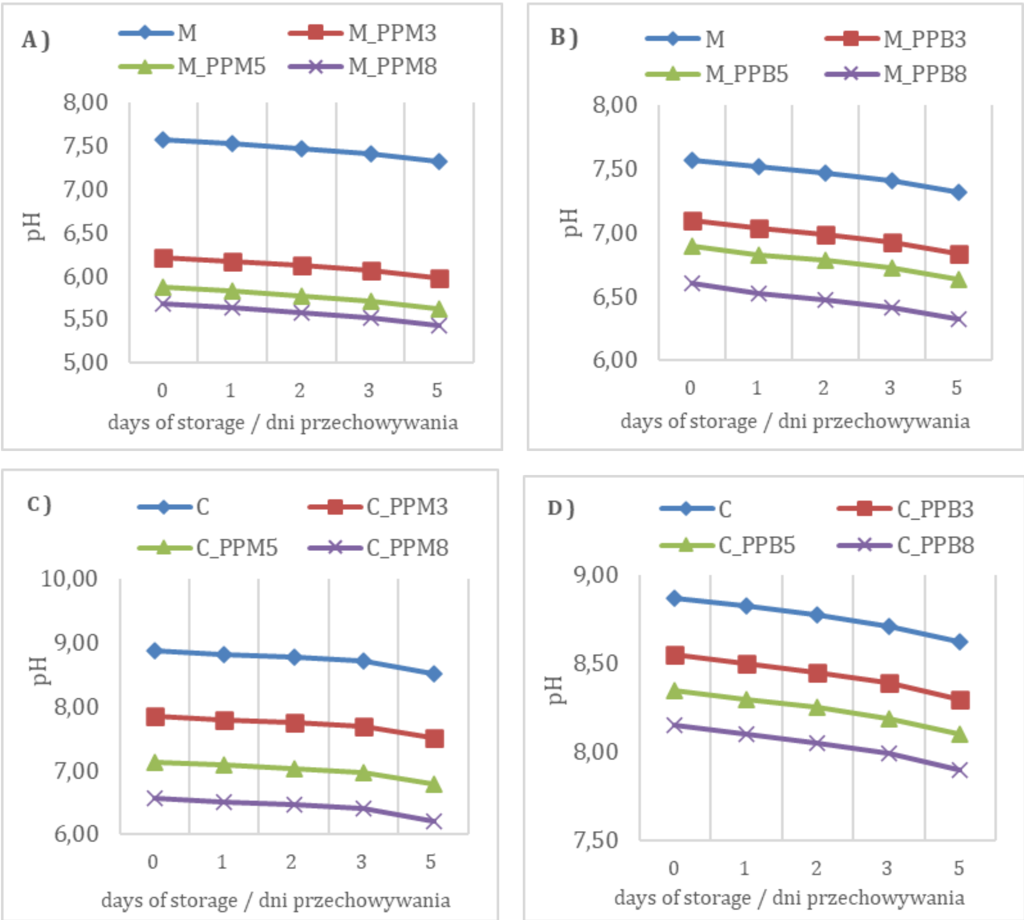

Figure 5. pH value of muffins and cookies samples and changes during storage (1÷5 days of storage) A) muffins with mandarin, B) muffins with banana, C) cookies with mandarin and D) cookies with banana

Rycina 5. Wartość pH próbek babeczek i ciastek oraz zmiany w czasie przechowywania (1-5 dni przechowywania) A) babeczki z mandarynką, B) babeczki z bananem, C) ciasteczka z mandarynką i D) ciasteczka z bananem

Regarding the pH values of the muffins (M) and cookies (C) supplemented with 3 %, 5 % and 8 % fruit peel powder (Figure 5), they ranged as follows: for the muffins, the minimum pH was 5.43 (M_PPM8 - day 5), while the maximum pH was 7.57 (M - day 1) across different concentrations. Conversely, the cookies exhibited a minimum pH range of 6.21 (C_PPM8 - day 5) to a maximum pH range of 8.87 (C - day 1) for the same concentrations of fruit peel powder. Incorporating banana peel powder led to higher pH values in both muffins and cookies compared to mandarin peel powder and their respective products. These findings align with the observations made by Urganci and Fatma [24], who examined the effects of pomegranate peel in biscuit formulation. They observed notable changes in pH and total acidity, attributing them to the addition of pomegranate peel, which led to a decrease in pH and a slight increase in total acidity. These observations parallel those made by us, suggesting that the incorporation of various fruit peel powders can alter the chemical composition of baked goods, potentially enhancing their quality and extending shelf life. Therefore, both studies highlight the importance of fruit peel powder as a functional ingredient in muffins and cookies, influencing their acidity, pH and overall characteristics.

The total color values (Figure 6) of the cereal-based products were analyzed and it was observed that they had positive values for L*, a* and b* components. The L* values ranged from 43.75 to 60.25, representing brightness, with a standard deviation of 5.58. The a* values ranged from 5.21 to 17.83, representing red color, with a standard deviation of 3.98. The b* values ranged from 16.45 to 40.21, representing yellow color, with a standard deviation of 6.53.

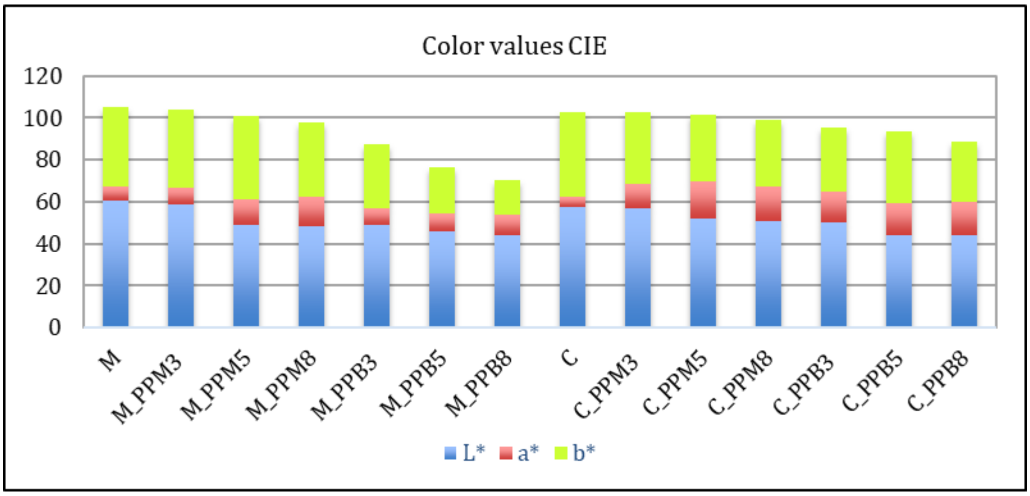

Figure 6. Color values CIE L*a*b* of the muffins and cookies enriched with mandarin and banana PP
Rycina 6. Wartości barwy CIE L*a*b* muffinów i ciastek wzbogaconych mandarynkowo-bananowym PP

Comparing the control samples (M and C) to the samples enriched with fruit peel powder, it was found that the L* and b* values were higher in the control samples. As the percentage of fruit peel powder increased, the L* and b* values decreased. Additionally, when mandarin peel powder was added, higher L* and b* values were obtained compared to banana peel powder. In contrast, the a* values showed an opposite trend. The a* values increased with the addition of fruit peel powder to the muffins and cookies. During storage, slight changes in the a* values were observed. The results of the study suggest that the addition of fruit peel powder significantly influenced the color characteristics of the cereal-based products. Specifically, the control samples exhibited higher brightness and yellow color compared to the samples enriched with fruit peel powder. However, the red color intensity increased with the incorporation of fruit peel powder. This suggests that the type of fruit peel used can also impact the color profile of the final products.

These findings align with a study conducted by Brigagão et al. [4], which explored the optimization of gluten-free muffins using various fruit peel flours. In their study, it was found that the addition of pumpkin seed flour increased the L* value, hue angle and chroma of the muffins' crust and crumb. On the other hand, banana peel flour decreased these parameters.

In conclusion, the incorporation of fruit peel powder, such as mandarin and banana peels, into cereal-based products can alter their color characteristics due to the presence of pigments like carotenoids and anthocyanins. These changes in color may have implications for the overall sensory perception and acceptability of products.

Total bioactive compounds and antioxidant activity of value-added muffins and cookies

The content of total bioactive compounds and antioxidant activity of the muffins and cookies enriched with mandarin and banana peel powder were evaluated and the results are presented in Figure 7.

Figure 7 displays the values of total polyphenols, flavonoids and antioxidant activity measured using two tests: $ABTS^{\bullet+}$ and $DPPH^{\bullet}$. The results revealed that the total polyphenol (TP) content ranged from 99.4 to 304.8 mg GAE/100 g FW of the sample, with a standard deviation of 67.7. The total flavonoid (TF) content ranged from 31.4 to 92.5 mg CE/100 g FW of the sample, with a standard deviation of 17.9.

The total antioxidant activity, as determined by the DPPH test, ranged from 10.2 to 54.7 % inhibition, with a standard deviation of 13.6. The ABTS test showed a total antioxidant activity ranging from 21.2 to 82.3 % inhibition, with a standard deviation of 16.6. The addition of fruit peel powder contributed to an increase in the content of total polyphenols, flavonoids and antioxidant activity, with values up to 2.7-fold higher than the control samples. Overall, the cookies exhibited higher values compared to the muffins in terms of total bioactive compounds and antioxidant activity.

Furthermore, the mandarin peel powder had a greater impact on enhancing these bioactive compounds and antioxidant activity compared to the banana peel powder. The magnitude of the increase depended on the amount of fruit peel powder added, with the order being PPB3 < PPB5 < PPB8 and PPM3 < PPM5 < PPM8. These findings indicate that the incorporation of the mandarin and banana peel powder into the muffins and cookies resulted in a significant boost in the levels of total polyphenols,

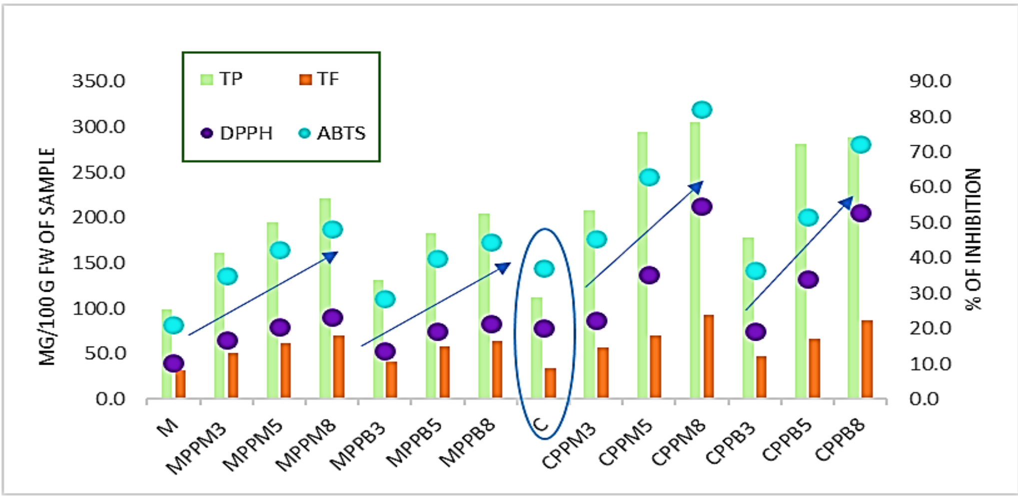

Figure 7. Total bioactive compounds and antioxidant activity of muffins and cookies enriched with mandarin and banana peel powder

Rycina 7. Suma składników bioaktywnych i aktywność przeciwutleniająca babeczek i ciasteczek wzbogaconych sproszkowaną skórką mandarynki i banana

flavonoids and antioxidant activity. These bioactive compounds and antioxidant properties are attributed to the presence of phytochemicals, such as phenolic compounds and flavonoids, in the fruit peel powder. The findings of our research align with those of other studies. These studies collectively highlight the significant contribution of fruit peel powder to enhancing the bioactive compounds and antioxidant activity of various food products, including muffins and cookies. Chakraborty et al. [5] emphasized the richness of polyphenols in unprocessed banana peels, corroborating our findings regarding the potent source of bioactive compounds in banana peel powder-enriched muffins and cookies. Additionally, Rockström et al. [21] emphasized the polyphenol content of fruit peels, supporting the notion that these peels are valuable sources of bioactive compounds, including polyphenols, which contribute to the enhanced nutritional profile of baked goods. Moreover, Wedamulla [25] demonstrated the positive impact of incorporating mandarin and banana peels into baked products, aligning with the focus of our research on the beneficial effects of fruit peel powder enrichment on antioxidant activity. Similarly, Giri et al. highlighted the improvement in nutritional value, particularly in terms of fiber content, phenols and antioxidant activity, through the use of pomegranate peel powder in muffins [8]. Furthermore, Kaur et al. [11] provided insights into the antioxidant activity and total phenol content enhancement in gluten-free muffins enriched with apple peels, reinforcing the broader consensus regarding the beneficial effects of fruit peel inclusion in baked goods. Overall, these studies collectively underscore the potential of fruit peel powder as a functional ingredient for enhancing the nutritional quality and health benefits of bakery products, consistent with our research findings. Further exploration into the bioavailability and health effects of these enriched compounds upon consumption would be valuable for future research endeavors.

Sensorial characteristics of value-added muffins and cookies

The results for the sensorial characteristics of the muffins and cookies enriched with mandarin and banana peel powder are presented in Figure 8.

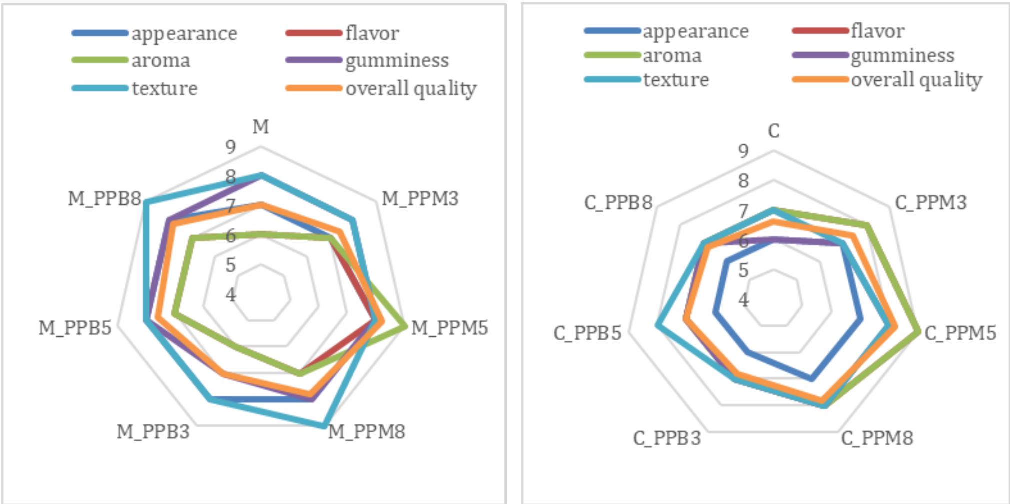

Figure 8. Sensorial characteristics of muffins and cookies at the time of production (day 0) and after 1÷5 days of storage

Rycina 8. Charakterystyka sensoryczna babeczek i ciasteczek w momencie produkcji (dzień 0) i po 1–5 dniach przechowywania

The sensorial characteristics of the muffins and cookies enriched with mandarin and banana peel powder were evaluated using a 9-point hedonic scale. The panelists rated the products based on appearance, flavor, aroma, gumminess, texture and overall quality. The results showed that the values for these sensory attributes ranged from 6 to 9, with standard deviations ranging from 0.53 to 0.91.

In terms of appearance, the products received ratings between 6 and 8, indicating that they were visually appealing. Flavor and aroma were also well-received, with ratings ranging from 6 to 9, suggesting a pleasant taste and aroma. Gumminess, which refers to the texture and chewiness of the products, received ratings between 6 and 8. Texture, including the overall mouthfeel, was rated between 7 and 9, indicating a desirable texture. When considering the overall quality, the products received ratings ranging from 6.6 to 8.2, with a standard deviation of 0.53. These scores demonstrate that the panelists found the products to be of good quality and likable. Regardless of the degree of the addition of the mandarin and banana peel powder, the cereal-based products were generally well-accepted by the panelists.

The results suggest that the addition of fruit peel powder, such as the one from mandarins and bananas, had a beneficial effect on the sensorial characteristics of the products. The samples with added mandarin peel powder (MPPM5 and CPPM5) obtained the highest mean score for overall quality, indicating that they were particularly favored by the panelists. The samples with banana peel powder also received higher scores for overall acceptability compared to the control samples (M and C), although they were slightly lower than the scores for the samples with mandarin peel powder. These findings demonstrated that the incorporation of mandarin and banana peel powder into the muffins and cookies could enhance the sensorial attributes of the products, resulting in the products that were well-liked and deemed of good quality by the panelists. These results further support the potential of fruit peel powder as an ingredient for improving the sensory experience of baked goods. The findings from the study on the sensorial characteristics of the muffins and cookies enriched with mandarin and banana peel powder align with similar research conducted by other authors. In a study by Brigagão et al. [4] gluten-free muffins were improved using pineapple peel, banana peel and pumpkin seed flour. Formulations with pineapple peel flour and a mix of pineapple peel flour and pumpkin seed flour were well-liked by consumers, offering both nutritional benefits and expanding the variety of gluten-free options. Another study by Kaur et al. [11] explored the use of apple peel in muffins. The analysis revealed that increasing the level of apple peel addition resulted in muffins with increased firmness, springiness and chewiness. Sensory panelists favored muffins with apple peel inclusion due to higher taste scores, attractive color and better texture parameters. Additionally, enriched muffins using pomegranate peel powder were deemed acceptable, indicating its potential to enhance physicochemical properties and shelf life [8]. In conclusion, the incorporation of fruit peel powders, such as the ones from mandarins, bananas, pineapples, apples and pomegranates, into baked goods has been shown to positively impact their sensory characteristics and nutritional profile, leading to products that are well received by consumers. These studies collectively underscore the potential of utilizing fruit peel powders as valuable ingredients in bakery formulations, offering both sensory and nutritional benefits for consumers.

Conclusion

1. The utilization of fruit peel powder from banana and mandarin peels in the muffins and cookies at different concentrations (3 %, 5 % and 8 %) offered a multitude of advantages (nutritional and functional benefits). The incorporation of fruit peel powder led to enhancements in protein content, total fat, total carbohydrates, total

ash and total vitamin C content compared to the control samples. Additionally, fruit peel powder acted as a water-binding agent, resulting in decreased moisture content and water activity, potentially extending the shelf life of the baked goods. Mandarin peel powder particularly impacted various physico-chemical characteristics more significantly than banana peel powder, especially as regards the vitamin C content.

2. The addition of fruit peel powder substantially boosted the levels of total polyphenols, total flavonoids and antioxidant activity in the products, suggesting potential health benefits. Despite these improvements, the sensory attributes of the baked goods remained appealing, with positive ratings for appearance, flavor, aroma, texture and overall quality.
3. Overall, integrating fruit peel powder represents a sustainable strategy to minimize food waste, while enhancing the nutritional profile and functional properties of baked products. Further exploration could delve into assessing the bioavailability and health effects of these bioactive compounds, as well as optimizing formulations to maximize the utilization of fruit peel powder in diverse culinary applications.

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ZRÓWNOWAŻONE ZASTOSOWANIE PRODUKTÓW NA BAZIE ZBÓŻ POPRZEZ WYKORZYSTANIE ODPADÓW OWOCOWYCH

S t r e s z c z e n i e

Wprowadzenie. Przemysł przetwórstwa owocowo-warzywnego odgrywa kluczową rolę w przemyśle rolno-spożywczym. Obecnie duże ilości wyrzucanych owoców i odpadów przyciągają uwagę kilku sektorów na całym świecie, nie tylko ze względu na obawy związane z wpływem na środowisko, ale także ze względu na dużą zawartość składników odżywczych i związków bioaktywnych, jakie mogą dostarczyć te niejadalne części. W pracy przeanalizowano możliwość wykorzystania odpadów owocowych poprzez dodanie sproszkowanych skórek bananów i mandarynek (PP) do produktów na bazie zbóż w celu wspierania zrównoważonego rozwoju i zdrowej diety. Skórki bananów i mandarynek przetworzono na proszek i dodano do babeczek i ciastek w stężeniach 3 %, 5 % i 8 %. Analizę próbek przeprowadzono w dniu przygotowania oraz po 1, 2, 3 i 5 dniach przechowywania.

Wyniki i wnioski. Kompleksowe analizy fizykochemiczne wykazały poprawę właściwości odżywczych i funkcjonalnych w porównaniu z próbkami kontrolnymi. W szczególności dodatek sproszkowanych skórek spowodował podniesienie wartości energetycznej, poprawę jakości odżywczej poprzez zwiększenie zawartości białka (do 12,8 %), tłuszczu całkowitego (do 7,84 %), węglowodanów ogółem (do 11,4 %), popiołu całkowitego (do 76,9 %), a całkowita zawartość witaminy C wzrosła aż 3,95-krotnie. Ponadto, proszek ze skórek owoców działał jako środek wiążący wilgoć, zmniejszając zawartość wilgoci i aktywność wody, potencjalnie wydłużając okres przydatności produktu do spożycia. Proszek ze skórek mandarynki wywierał bardziej wyraźny wpływ na właściwości fizykochemiczne w porównaniu do proszku ze skórek banana. Ponadto dodatek sproszkowanych skórek owoców znacznie podniósł poziom polifenoli, flawonoidów i aktywność przeciwutleniającą, osiągając wartości aż 2,7-krotnie wyższe niż w próbkach kontrolnych. Oceny sensoryczne potwierdziły akceptację produktów, uzyskując ogólną ocenę jakości od 6,6 do 8,2 w 9-punktowej skali hedonicznej. Badanie to potwierdza przydatność proszku ze skórek owoców jako zrównoważonego składnika ograniczającego marnowanie żywności, przy jednoczesnej poprawie profilu odżywczego i funkcjonalności produktów na bazie zbóż.

Słowa kluczowe: utylizacja odpadów owocowych, proszek ze skórek, produkty na bazie zbóż, wzmocnienie odżywcze, zrównoważony rozwój, aktywność przeciwutleniająca