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FUNCTIONAL BISCUITS ENRICHED WITH POTATO PEEL POWDER: PHYSICAL, CHEMICAL, RHEOLOGICAL, AND ANTIOXIDANT PROPERTIES

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biscuits, potato peel powder, total phenols, antioxidant activity, organoleptic properties

ABSTRACT
This research aimed to replace wheat flour with potato peel powder (PPP) at different levels (3, 5, 7, 10, 30, and 50%). An effect of PPP on physical, chemical, rheological, and antioxidant properties of biscuit samples was investigated. The results show that the PPP sample had a significantly higher content of total sugar, protein and ash, and a lower content of moisture (15.68g/100g dry weight, 15.32 g/100g dry weight, 9.11%, 8.35%, respectively) compared with the wheat flour sample. Also, a higher total phenolic content and antioxidant activity (71.12 mg Gallic acid equivalent / 100g dry weight and 68.39%, respectively) was observed in the PPP sample. The highest percentage of PPP addition (50%) exerted the greatest significant effect on the content of total sugar, protein, moisture, ash, total phenols, and antioxidant activity compared with the control sample and other biscuit samples leading to their increase to 50.90 g/100g dry weight, 12.74 g/100g dry weight, 5.56%, 2.39%, 41.71 mg Gallic acid equivalent / 100g dry weight, 59.72%, respectively. A decrease in the L*, a*, b*, C*, h and BI values, and an increase in ΔE values were observed with replacing wheat flour with PPP. The 3% and 5% replacement rates contributed to improving most organoleptic characteristics (general acceptability, color, taste) compared to the samples with the highest studied percentages (30% and 50%). Although the highest percentages of PPP addition led to lower scores for sensory characteristics, all studied samples were acceptable from the sensory point of view, except the samples with the 50% replacement rate in terms of their taste and color.

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ФУНКЦИОНАЛЬНОЕ ПЕЧЕНЬЕ, ОБОГАЩЕННОЕ ПОРОШКОМ КАРТОФЕЛЬНОЙ КОЖУРЫ: ФИЗИЧЕСКИЕ, ХИМИЧЕСКИЕ, РЕОЛОГИЧЕСКИЕ И АНТИОКСИДАНТНЫЕ СВОЙСТВА

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КЛЮЧЕВЫЕ СЛОВА:
печенье, порошок картофельной кожуры, общие фенолы, антиоксидантная активность, органолептические свойства

АННОТАЦИЯ
Цель этой работы состоит в описании и исследовании ранее неизвестного явления самосегментации молочного сгустка в сыродельной ванне открытого типа. На основе анализа кинетики гелеобразования определено, что самосегметация геля начинается вблизи гель-точки, развивается в течение нескольких десятков секунд и закрепляется по мере уплотнения геля. Сегменты в молочном сгустке не имеют определённой правильной формы, их средний размер вариабелен в пределах от 5 до 50 см. Форма и размеры сегментов не повторяются и не коррелируют с видом вырабатываемого сыра. Смещение сегментов молочного сгустка в сыродельной ванне относительно друг друга по высоте составляет от 0,5 до 2 мм. Ширина граничного слоя между сегментами сгустка увеличивается в процессе вторичной фазы гелеобразования от 3 до 10 мм. В результате проведенных экспериментальных исследований показано, что самосегментация молочного геля вызывается термогравитационной конвекцией, образующей циркуляционные ячейки Бенара. Предложено описание возможного механизма самосегментации молочного геля в сыродельных ваннах открытого типа. Отмечена действенная роль жировых шариков в механизме самосегментации молочного сгустка. Высказано предположение, что самосегментация молочного сгустка в сыродельной ванне может вызвать некоторые органолептические дефекты в готовом сыре, в частности неравномерность текстуры и неравномерность цвета.

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1. Introduction

The potato (*Solanum tuberosum L.*) belongs to the Solanaceae family, originated in South America circa 500 B.C [1], and is the fourth most widely grown crop in the world [2]. Global potato production reached 367.75 million tones [3].

On an industrial scale, potato products (e.g., potato fries, potato chips, mashed sweet potatoes) generate between 3 and 5% of waste (peel) [1]. Arapoglou et al. [4] reported that the losses (%) caused by potato peeling ranged between 15 and 40%, depending on the peeling method (i.e., steam peeling, alkali peeling, or abrasion). Typical potato processing plant generate from 6 to 10% of potato peel waste during the peeling process, and 15% of waste are caused by defect removal, trimming, and cutting. Potato peels contain fiber between 9.7 and 68% of its total weight [5]. Potato peel has a protein content of 18%, ash content of 6% on a dry weight basis, and produce 63% of fiber on a dry weight basis by manual peeling [6]. Additionally, potato peel waste contains high concentrations of minerals (potassium, calcium, magnesium, iron, and zinc), as the potassium content reaches 15.7 g/kg, calcium 3.05 g/kg, magnesium 1.09 g/kg, iron 388 mg/kg, zinc 18.65 mg/kg, copper 12.05 mg/kg, manganese 14 mg/kg, chromium less than 5 mg/kg, lead less than 5 mg/kg [7].

Potato peels are an excellent source of numerous important functional components, such as phenolic compounds. For example, Sabeena Farvin et al. [8] found that potato peel extracts are rich in their content of phenolic acids. The ethanolic extract of potato peel contained gallic acid (0.9 mg/g dry weight), protocatechuic acid (7.38 mg/g dry weight), gentisic acid (15.42 mg/g dry weight), chlorogenic acid (0.43 mg/g dry weight), vanillic acid (1.10 mg/g dry weight), syringic acid (0.64 mg/g dry weight), caffeic acid (2.79 mg/g dry weight), salicylic acid (0.11 mg/g dry weight), p-coumaric acid (0.58 mg/g dry weight). Joly et al. [9] stated that potato peels contain several important phenolic antioxidants that can be used as natural antioxidants. The content of polyphenols in potato peels is around 10 times higher than in flesh [10]. The antioxidant potency of the freeze-dried extract of potato peel was also found by Singh et al. [11]. Potato peel is an important source of dietary fiber, which accounts for about 40–45% of its dry weight [12].

Dietary fiber is an indigestible component that makes up the plant cell wall. The botanists define fiber as part of the plant organs, consumers as a substance with beneficial effects on human health, while dietary fiber from a manufacturing point of view is an object of marketing. Fiber consists of hemicellulose, cellulose, lignin, oligosaccharides, pectins, gums, and waxes. The diets with a high content of dietary fiber have a positive effect on human health [13]. Dietary fibers act as a protective agent against several diseases, including cardiovascular diseases, diverticulosis, constipation, irritable colon, colon cancer and diabetes [14,15]. It is recommended for healthy adults to intake 20–35 g of dietary fiber per day [16].

Thus, many studies aimed to create new applications of potato peel in a wide range of food products. For example, the addition of fiber in the bread industry contributed to an increase in the values of hydration of flour with water. It was also noted that replacing wheat bran with potato peels led to the superiority of bread in terms of its content of minerals and total dietary fibers [17]. Also, the cake prepared using 25% of apple pomace and wheat flour was of acceptable high quality [18]. Toma et al. [17] reached the best results when the levels of replacing wheat flour with potato peel powder ranged between 10 and 15%. The resulting bread was darker and tougher compared to the control. No significant sensory changes were observed at the 10% replacement rate compared to the control. Han et al. [19] reported that when wheat flour was replaced with 10, 15, and 20% of potato peel powder in the cookies, the glycoalkaloid content was 6.27, 9.40, and 12.54 mg, respectively. These values are considered safe for the human body and sufficient for the production of functional cookies according to USDA guidelines. Replacing wheat flour in the cookie samples with 10% potato peel powder gave the highest scores in sensory evaluation. Shagufta et al. [1] showed the physical properties (width, thickness, and spread ratio) of biscuits reinforced with potato peel powder. The mean values ranged from 40.81 to 45.22 for width, from 9.74 to 10.97 for thickness and from 37.20 to 46.43 for spread ratio during 90 days of storage.

Therefore, due to the fact that potato peels contain many components beneficial for health, large amounts of potato peels produced in the form of waste, and the lack of local studies on the possibility of converting potato waste (peels) into food products with added value containing antioxidants, proteins, and dietary fibers, the research objectives were as follows: 1) studying quality characteristics of wheat flour and potato peel powder produced; 2) studying quality characteristics, sensory characteristics, and color indicators of the resulting biscuit samples; 3) studying an effect of replacing wheat flour with potato peel powder in different proportions on the rheological properties of the resulting dough.

2. Materials and Methods

2.1. Materials

Potatoes were purchased from the local market of Damascus, and the peels were obtained by peeling the potatoes of the Spunta variety (*Solanum tuberosum var. spunta*). The materials needed to manufacture the biscuits (wheat flour, butter, sodium bicarbonate, sodium chloride, sugar) were purchased from the local market of Damascus.

2.1.1. Preparation of potato peel powder

Potato peel powder was prepared according to the method described earlier [20]. Potato tubers were washed with plain water and peeled manually. The percentage of peels obtained was on average 13% of the tuber weight. The peels were dried using a hot air-drying oven (Köttermann, 2717, 2701, Gemini bv, Dutch company, found in the Faculty of Agriculture Laboratories, Department of Food Sciences at Damascus University) at 60 °C for 12 hours to constant moisture. After drying, the dried peels were ground using a mill (Moulinex, Y44, Moulinex, France) until fine (Figure 1), then sieved through a fine sieve (60 mesh) to obtain a

Figure 1. **Potato peel powder**
Рисунок 1. **Порошок картофельной кожуры**

fine homogeneous powder and stored in opaque sealed containers in a cool dry place until the time of manufacture and testing.

2.2. Methods

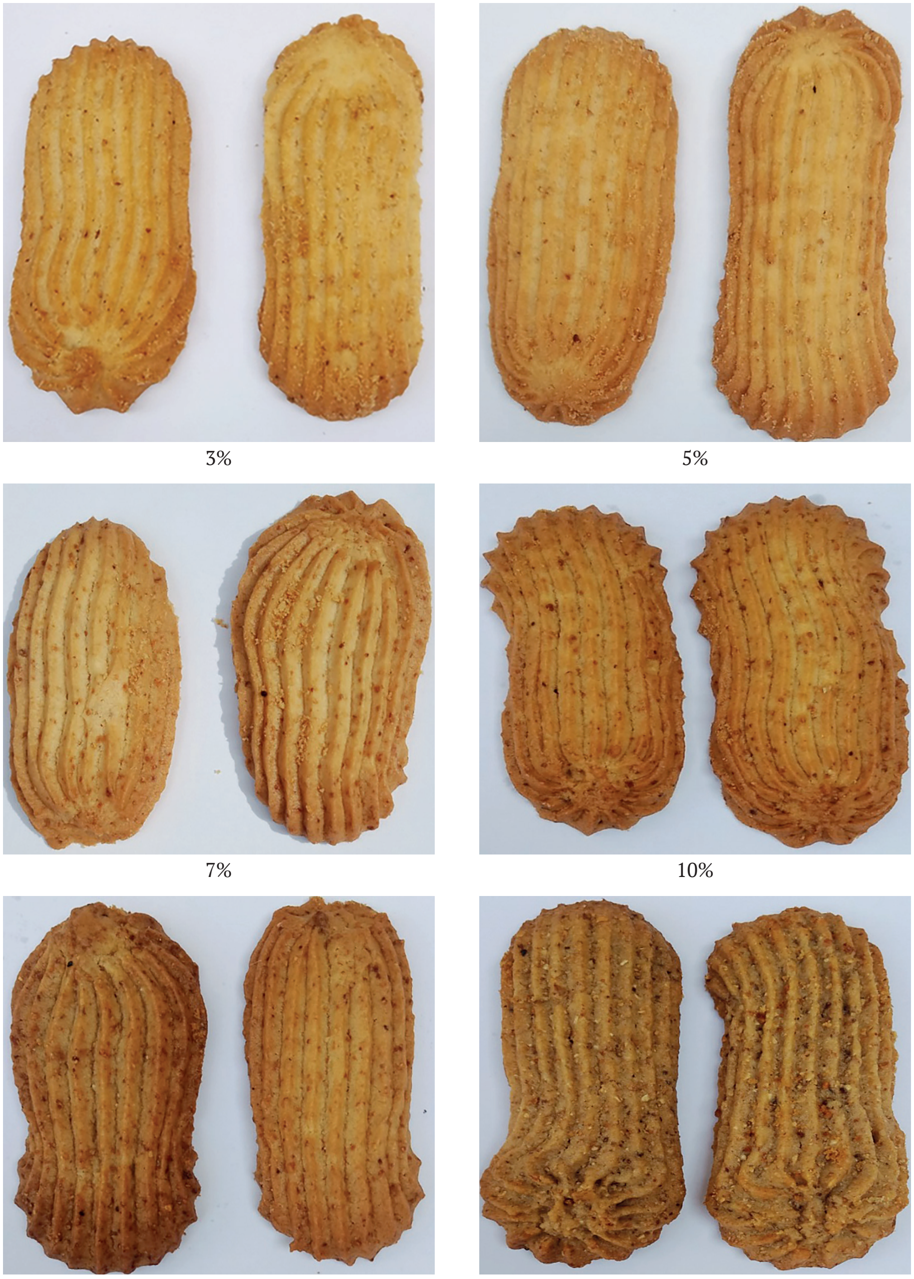
2.2.1. Preparation of biscuits

The control biscuits were prepared from wheat flour according to the method described by Dhingra et al. [16] and Tyagi et al. [21] with some modifications. The components of the control biscuits were as follows: 100 g of wheat flour (72% extraction), 55 g sucrose sugar, 50 g butter, 0.50 g sodium chloride, 1 g sodium bicarbonate, 1 g baking powder, 8.9 g glucose sugar and 150 ml of water. The sugar and butter were mixed using a mixer for 3 minutes, then sodium bicarbonate and sodium chloride were dissolved in water at room temperature, then they were mixed well for 5–6 minutes to obtain a homogeneous mixture (Moulinex, QA311127, France). All ingredients were mixed using a mixer (Moulinex, QA311127, France) with baking powder and sifted flour for 3 minutes. The dough was cut into pieces of suitable sizes, shaped using special molds and baked at 180 °C for 11–12 minutes (WattarB9050S, Wattar, Syria). After baking, the biscuits were cooled to room temperature (28 to 30 °C), then the biscuits were packed in airtight containers until the analyses were carried out.

The other biscuit samples were prepared by replacing wheat flour with different percentages of potato peel powder (3, 5, 7, 10, 30, 50%) according to the aforementioned method (Figure 2).

2.2.2. Chemical analysis

Moisture was estimated according to the method given in AACC [22] No. (44–15.02) by drying at 105 °C until constant weight using a hot air oven (Köttermann, model 2701), and ash content was estimated according to the method mentioned in AACC [22] No. (08–01) by burning the sample at a temperature of 550 °C until all the organic matter was burned using a Wise-Therm incinerator. The total protein was determined by the Kjeldahl method [23]. Total sugars in the samples were estimated using the reactions of the reversibility (Fehling's test), whereby sucrose is hydrolyzed into monosaccharides (glucose and fructose) to be measured [23].



3% 5%

7% 10%

30% 50%

Figure 2. **Wheat flour with different percentages of potato peel powder (3, 5, 7, 10, 30, 50%)**

Рисунок 2. **Пшеничная мука с различными процентами порошка картофельной кожуры (3, 5, 7, 10, 30, 50%)**

2.2.3. Color analysis

Mapping of color indices (L^*, a^*, b^*): The color indices (L^*, a^*, b^*) were measured using the Hunter Lab device (Chroma meter CR-410, Japanese) according to Bilgiçli and Levent [24], where the symbols denote: L^* (Lightness), a^* (Redness/Greeness), b^* (yellowness/blueness). The value of the indicators (h and C^*) was calculated according to Wrolstad et al. [25] from the following two relationships:

$$\text{Hue angle } (h) = \tan^{-1} (b^*/a^*) \quad (1)$$

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

The total change in color was calculated according to Saricoban and Yilmaz [26] from the following relationship:

$$\Delta E^* = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (3)$$

The value of the tan index was calculated according to Mohammadi et al. [27] from the following relationship:

$$\text{Browning Index } (BI) = [100\ (X^* - 0.31)]/\ 0.17 \quad (4)$$

where:

$$X^* = (a^* + 1.75\ L^*)/\ (5.645\ L^* + a^* - 3.012\ b^*) \quad (5)$$

2.2.4. Texture profile analysis (TPA) of biscuits

Hardness, adhesiveness, resilience, and fracturability of biscuits were measured using the Brookfield Texture Analyzer (CT3, Brookfield, USA) in the Agriculture Research Center, Giza, Egypt [28].

2.2.5. Mixolab and Alveograph experiments

Mixolab and Alveograph experiments were conducted in the Food Science Department, Faculty of Agriculture, Cairo University, Egypt.

Rheological analysis of dough, the mixing behavior of doughs obtained from wheat flour and blends were studied using Mixolab (Chopin, Tripette, Renaud, Paris, France). It measures in real-time the torque (expressed in Nm) produced by the passage of dough between the two kneading arms, hence allowing the study of its rheological behavior [29]. For the assays, 50 g of wheat flour was placed into the Mixolab bowl and mixed with the amount of water needed to reach the target consistency (1.1 Nm). When potato peel powder (PPP) was tested, 3, 5, 7, 10% of wheat flour were replaced by PPP. The specific protocol (Mixolab Standard) used for dough testing consisted of 30 min mixing at 30 °C and the mixing speed during the entire assay was 80 rpm. Two batches were made for each sample. Parameters recorded from the Mixolab curve included: water absorption or the amount of water required to reach the consistency of 1.1 Nm (expressed as milliliters per 100g of flour at 14.0% moisture mass fraction), dough development time or time to reach the maximum consistency, and stability of the dough during mixing that indicates the elapsed time, at which dough retained the maximum consistency.

Rheological properties of wheat flour were determined by a Chopin MA 82 alveograph (according to ICC Standard 55 30–3). Each alveograph chart was analyzed for four factors: P — the maximum overpressure needed to blow the dough bubble — expresses dough elasticity, L — the average abscissa at bubble rupture — expresses dough elasticity, P/L — alveograph ratio and W — the baking strength. The variables represent the average of five curves from five dough patties [30]. The results of analysis were expressed by average, minimum, and maximum values and by the standard deviation in each sample set. Spectra were acquired with a NIRS6500 wavelength scanning instrument (NIR Systems, Inc., USA) using a small annular cup. The range of scanning was from 400 to 2500 nm, and wavelength increments of 2 nm were used. Diffuse reflectance was recorded as log 1/R. The average spectra from two scans obtained for each sample were utilized for calibration.

2.2.6. Determination of the antioxidant activity

The antioxidant activity was measured by estimating the free radical scavenging activity using the 2,2`-diphenyl 1,1-picryl hydrazyl (DPPH) radical scavenging assay according to Younis et al. [31].

2.2.7. Determination of total phenolic compounds

In extracting total phenols, the method of L. Wada and B. Ou [32] was employed, and the total phenols were estimated using the Folin Ciocalteu method according to [33, 34].

2.2.8. Functional properties

Water, emulsion, and oil absorption capacities (WAC, EAC, and OAC) of wheat flour and potato peel powder were determined using the AACC method 56–20 [35].

2.2.9. Sensory evaluation

Sensory tests were conducted by a group of 15 people (professors, students and staff from the Department of Food Science, University of Damascus) using the hedonic scale, identifying seven points (color, taste, smell, texture, melting in the mouth, fracture, and general acceptability) according to Akhtar et al. [36]. Sensory evaluation scores were given as follows: 1 — poor, 2 — acceptable, 3 — good, 4 — very good, 5 — excellent.

2.2.10. Statistical analysis

Experimental results were analyzed by analysis of variance (ANOVA) using XLSTAT software version 2014, 5.03 (Addinsoft, New York, NY, USA) in three replicates and expressed as the mean ± standard error of the mean. Differences between sample means with a p-value $\leqslant$ 0.05 were considered to be significant.

3. Results and Discussion

3.1. Chemical composition of wheat flour and potato peel powder

Table 1 presents the results of some chemical indicators for the studied samples (wheat flour and potato peel powder). The results show a lower moisture content in the potato peel powder sample compared with wheat flour (8.35%, 13.09%), respectively. These results are in agreement with [16], where the moisture of potato peel powder was 7.85%, and [37], where wheat flour moisture was 13.90%.

Table 1. **Some chemical indicators of wheat flour and potato peel powder samples**

Таблица 1. **Некоторые химические показатели образцов пшеничной муки и порошка картофельной кожуры**

Sample	Moisture%	Total sugar (g/100g) dry base	Protein (g/100g) dry base	Ash%
Wheat flour	13.09±0.10[a]	13.09±0.50[b]	11.45±0.89[b]	0.44±0.05[b]
Potato peel powder	8.35±0.32[b]	15.68±0.66[a]	15.32±0.77[a]	9.11± 0.10[a]

a and, b: small letters refer to significant differences (p $\leqslant$ 0.05) between the means.

It can be seen from Table 1 that the content of total sugars, ash, and protein in the sample of potato peel powder was 15.68 g / 100 g dry weight, 9.11%, and 15.32 g / 100 g dry weight, respectively. These results are in agreement with those in other studies. For example, the ash content was 9.03% in potato peel powder [7] and 0.46% in wheat flour [37], the percentage of protein was 15.71% on a dry weight basis in potato peel powder [38] and 11.32% in wheat flour [37]. Shagufta et al. [1] reported that the proximate composition of wheat flour and potato peel powder was as follows: 3.58 and 11.99% moisture, 6.92 and 0.52%

ash, 2.25 and 1.06% fat, 68.73 and 0.54% fiber, 12.16 and 10.81% protein, 4.97 and 86.06% carbohydrates, respectively. Leo et al. [39] showed that potato peel contained 10.76% protein, 10.56% ash, 4.98% fat, 4.97% carbohydrates, and 68.53% fiber. Sharoba et al. [14] found that wheat flour had 11.98% moisture, 11.85% protein, 1.05% fat, 0.51% ash, 0.54% fiber, 86.04% carbohydrates, while potato peel powder had 3.57% moisture, 6.91% ash, 2.25% fat, 12.17% protein, 73.25% fiber.

3.2. Effect of replacing wheat flour with potato peel powder on chemical indicators of biscuit samples

The results shown in Table 2 indicate that there was a significant effect of replacing wheat flour with potato peel powder at the replacement rate of 3% to 50% on percentages of protein, moisture, ash, and total sugars. The 50% replacement led to the highest content of total sugars, protein, moisture and ash (50.90 g/100 g dry weight, 12.74 g/100 g dry weight, 5.56%, 2.39%, respectively) in the biscuit samples fortified with potato peel powder compared to their content in the control samples (40.62 g/100g dry weight, 7.42 g/100g dry weight, 4.76%, 0.70%, respectively).

Table 2. **Effect of replacing wheat flour with potato peel powder on chemical indicators of biscuit samples**

Таблица 2. **Влияние замены пшеничной муки на порошок картофельной кожуры на химические показатели образцов печенья**

Samples	Moisture%	Total sugar (g/100g) dry base	Protein (g/100g) dry base	Ash%
Control	4.76±0.50[e]	40.62±0.23[g]	7.42±0.10[ef]	0.70±0.10[d]
Biscuits fortified with 3% PPP	4.84±0.38[de]	41.42±0.55[ef]	7.50±0.25[ef]	0.75±0.17[d]
Biscuits fortified with 5% PPP	4.90±0.12[d]	41.95±0.66[e]	7.80±0.06[e]	0.79±0.28[d]
Biscuits fortified with 7% PPP	4.98±0.52[d]	42.48±0.55[d]	8.10±0.14[cd]	0.84±0.18[c]
Biscuits fortified with 10% PPP	5.03±0.46[bc]	43.28±0.55[c]	8.60±0.14[c]	0.89±0.12[c]
Biscuits fortified with 30% PPP	5.28±0.17[b]	47.59±0.55[b]	10.16±0.14[b]	1.59±0.06[b]
Biscuits fortified with 50% PPP	5.56±0.23[a]	50.90±0.55[a]	12.74±0.14[a]	2.39±0.10[a]

The same letters within the same column indicate that there are no significant differences between the means at the confidence level ($p \leqslant 0.05$). PPP — potato peel powder

This may be due to the high content of proteins, sugars, ash, and fiber in potato peel powder compared with wheat flour. An increase in the moisture content in biscuits with a higher percentage of potato peel powder was attributed to the high water-holding capacity of potato peel as the fiber has a strong water absorption capacity [1] and the corresponding large content of fiber in the biscuit samples with potato peel powder [40]. The high ash percentage is also due to the high fiber content in the samples with a high replacement rate [41].

3.3. Total phenol content and antioxidant activity of biscuit samples

Wheat flour is a good source of calories and various nutrients on its own, but its antioxidant capacity is low because it is refined during processing [42]. Biscuits made with refined wheat flour and other ingredients lack phytochemicals and dietary fiber, so wheat flour must be combined with potato peel powder to increase its antioxidant capacity.

Table 3 demonstrates the effect of replacing wheat flour with different percentages of potato peel powder on the content of total phenols and the antioxidant activity of the studied biscuit samples estimated using the free radical DPPH. The content of the total phenols and the antioxidant activity were 71.12 mg Gallic acid equivalent /100g dry weight and 68.39%, respectively, in the potato peel powder samples and 3.28 mg Gallic acid equivalent /100g dry weight and 13.37%, respectively, in the samples of wheat flour.

Table 3. **Effect of replacing wheat flour with different percentages of potato peel powder on the content of total phenols and the antioxidant activity of the studied biscuit samples**

Таблица 3. **Влияние замены пшеничной муки различными процентами порошка картофельной кожуры на содержание общих фенолов и антиоксидантную активность исследованных образцов печенья**

Samples	TPC (mg/100g dry weight)	Antioxidant activity (%)
Wheat flour	3.28±0.60	13.37±0.52
PPP	71.12±0.87	68.39±0.26
Control biscuits	5.86±0.23[e]	20.06±0.35[e]
Biscuits with 3% PPP	7.43 ±0.75[f]	21.27±0.40[f]
Biscuits with 5% PPP	10.26±0.42[e]	25.23±0.65[e]
Biscuits with 7% PPP	13.86±0.16[d]	40.43±0.17[d]
Biscuits with 10% PPP	17.05±0.68[c]	42.85±0.33[c]
Biscuits with 30% PPP	33.28±0.64[b]	54.71±0.44[b]
Biscuits with 50% PPP	41.71±0.58[a]	59.72 ±0.61[a]

The same letters within the same column indicate that there are no significant differences between the means at a confidence level ($p \leqslant 0.05$). TPC — total phenol content, PPP — potato peel powder

The high antioxidant activity in biscuits fortified with potato peel powder is due to a higher antioxidant content of potato peel powder in comparison with wheat flour. The Maillard reaction is responsible for the development of the brown pigments melanoidins during the baking process. Melanoidins possess the antioxidant properties. So the antioxidant activity of the potato peel biscuits may be enhanced by the Maillard reaction. Abdel-Aal and Rabalski [43] pointed out that free phenolic acids increased after baking, while bound phenolic acids decreased in bread and slightly changed in muffins and cookies. Whole grain products should be considered good sources of phenolic antioxidants, despite the fact that the effect of baking seems to depend on a type of baked product, type of phenolic, recipe, and baking conditions [43]. The dissociation of the bound phenolic moiety, which is followed by polymerization and oxidation reactions, as well as the formation of new phenolic compounds that were not present prior to thermal processing, can be the cause of an increase in the content of free phenolics during the process [44, 45, 46, 47]. The development of Maillard reaction products (MRPs) can also be responsible for an increase in the content of phenolic compounds [47]. It is necessary to note that certain products of the Maillard reaction have the reductone structures and the formation of MRPs can contribute to an increase in the total phenolic compounds in the Folin-Ciocalteu assay [48]. Bressa et al. [49] found that MRPs produced within the first 20 to 30 minutes of cooking had the high antioxidant capacity. An improvement in the antioxidant properties of naturally occurring compounds and formation of Maillard reaction products are probably responsible for an increase in the antioxidant capacity [47].

The results obtained are consistent with what was indicated by Rowayshed et al. [7] as the content of total phenols and the antioxidant activity of ethanolic extracts of potato peels were 75.67 mg Gallic acid equivalent /100g dry weight and 67.65%, respectively. Also, Almasri et al. [50] indicated that potato peels contain a high concentration of antioxidants such as phenolic acids (potato peel extracts had a phenolic content of 96.66 mg of Gallic acid per 100 g), so they have a high nutritional value. The potato peel fractions are considered a value-added ingredient in other foodstuffs to increase antioxidant intake by humans and have the potential to be used as antioxidant supplements in the pharmaceutical industry.

The addition of potato peel powder in different proportions (3–50%) contributed to a significant increase of 26.79%-611.77% in the total phenolic content and an increase of 6.03%-197.71% in the antioxidant activity compared with the control samples. Higher concentrations of potato peel powder in biscuits led to a higher total phenolic content and a higher antioxidant activity in the studied samples. For example, the addition of 3%, 5%, 7%, 10% and 30% of potato peel powder resulted in an increase of 26.79%, 75.09%, 136.52%, 190.96% and 467.92%, respectively, in total phenols and an increase of 6.03%, 25.77%, 101.55%, 113.61% and 172.73%, respectively, in the antioxidant activity. Biscuit samples fortified with potato peel powder at a 50% replacement rate showed a marked increase of 611.77% in the total phenolic content (41.71 mg Gallic acid equivalent /100g dry weight) and an increase of 197.71% in the antioxidant activity (59.72%) compared with the control biscuit samples (5.86 mg Gallic acid equivalent /100g dry weight and 20,06%, respectively).

3.4. Color indicators of the studied biscuit samples

Table 4. **Effect of replacing wheat flour with different percentages of potato peel powder on the color indicators of the studied biscuit samples**

Таблица 4. **Влияние замены пшеничной муки различными процентами порошка картофельной кожуры на показатели цвета исследованных образцов печенья**

Samples	L*	a*	b*	C*	BI	h	ΔE*
Wheat flour	93.91	-1.82	14.49	14.61	14.90	-82.84	—
PPP	51.56	3.03	13.25	13.59	33.48	77.12	—
Control biscuits	67.01^{a}	6.36^{a}	34.83^{a}	35.41^{d}	77.63^{a}	79.65^{a}	—
Biscuits with 3% PPP	66.91^{b}	4.68^{b}	27.96^{c}	28.35^{a}	57.88^{d}	80.50^{b}	7.07^{f}
Biscuits with 5% PPP	63.07^{c}	3.68^{c}	28.33^{b}	28.57^{b}	62.16^{c}	82.60^{c}	8.06^{e}
Biscuits with 7% PPP	62.05^{d}	5.04^{d}	26.78^{d}	27.25^{c}	61.01^{b}	79.34^{d}	9.55^{d}
Biscuits with 10% PPP	53.46^{e}	5.88^{e}	18.44^{e}	19.35^{d}	49.64^{e}	72.31^{e}	21.27^{c}
Biscuits with 30% PPP	46.56^{f}	4.94^{f}	14.19^{f}	15.03^{a}	43.55^{f}	70.80^{f}	29.09^{b}
Biscuits with 50% PPP	43.25^{g}	4.71^{g}	11.64^{g}	12.56^{b}	38.85^{g}	67.97^{g}	33.24^{a}

The same letters within the same column indicate that there are no significant differences between the means at a confidence level ($p \leqslant 0.05$). L*: Lightness; a*: Redness; b*: Yellowness; C*: Color Intensity; h: Hue Angle; BI: Browning Index; ΔE*: total change in color. PPP — potato peel powder

Table 4 shows an effect of replacing wheat flour with different percentages (3–50%) of potato peel powder on the color indicators of the studied biscuit samples. Adding potato peel powder led to significant changes in all studied color indicators for manufactured biscuit samples compared to the control sample. L*, a*, b*, C*, h and BI values decreased and ΔE* rose with an increase in the proportions of replacing wheat flour with potato peel powder, and this gave the biscuits a darker color compared to the control biscuits, while the control samples had higher L*, a*, b* and C* values. Additionally, the yellowness and brightness of the biscuits decreased due to the enzymatic browning. Brown pigments that occur during the browning and caramelization reaction, as well as temperature and cooking time, influence the color of biscuits.

The potato peel powder sample was characterized by higher values of a*, BI and h and lower values of b*, L* and C* compared with the wheat flour sample. Rowayshed et al. [7] reported that the L*, a* and b* values in the control biscuit samples were 63.58, 14.04 and 25.41, respectively. The addition of potato peel extract to the biscuits with concentrations ranging from 0.5% to 3% led to a reduction in the values of color indices compared to the control biscuits. The L*, a* and b* values were 62.96, 8.99 and 24.7, respectively, in biscuits enriched with the potato peel extract in a concentration of 0.5% and 53.33, 10.31 and 21.98, respectively, in biscuits enriched with the potato peel extract in a concentration of 3%. A decrease in the values of yellowness (b*) and brightness (L*) was due to browning [51]. Han et al. [19] indicated that replacement of wheat flour with potato peel in different proportions led to higher brightness (L*) values (90.97, 89.24 and 90.04) and lower a* (4.69, 5.13 and 3.85) and b* values (−9.49,—7.68 and −10.66) in the biscuit samples with the 10%, 15% and 20% replacement ratio, respectively, compared to the corresponding values of color indices in the control biscuits (83.88, 8.92 and 1.25, respectively).

3.5. Sensory properties of the studied biscuit samples

The results of studying the effect of replacing wheat flour with different percentages (3–50%) of potato peel powder on the sensory characteristics of the studied biscuit samples are presented in Table 5. As can be seen from the table, there was a significant effect of replacing wheat flour with potato peel powder on the sensory characteristics of the studied biscuit samples. The biscuit samples enriched with potato peel powder in different proportions were acceptable to the assessors from the sensory point of view as the sensory evaluation scores for all studied traits ranged between 2.1 and 4.7, excluding the samples with the 50% replacement, which were unacceptable for the panelists in terms of color and taste.

The samples with the 3% and 5% replacement rates had better sensory characteristics (general acceptance, color, taste) compared to the samples with the highest studied percentages (30% and 50%), which had poor sensory characteristics as the taste was unpalatable, the color was dark and unacceptable, and the solubility in the mouth was poor in the samples with higher percentages of potato peel powder compared to the control biscuit sample. The reason for a decrease in the color tone in the biscuit samples with the high percentage of potato peel powder maybe the brown color of potato peels, which became dark brown with the high temperature during baking. Similar results were obtained by Srivastava et al. [52], who found that the addition of sweet potato flour imparted the dark brown color to biscuits. Raymundo et al. [53] reported that the biscuits became darker with an increase in the level of added fiber, and this effect can be explained by the non-enzymatic browning when wheat flour was replaced with fiber.

The scores for taste or flavor of the product decreased significantly, especially in the samples with the 30% and 50% replacement rate, probably due to the high content of glycol alkaloids (alpha- chaconine and alpha- solanin) at higher percentages of fortification with potato peels. The biscuits that contained a high amount of potato peel powder showed contradictory results regarding texture. A decrease in the general acceptance of biscuits with an increase in the level of potato peel powder is due to the total effect on taste, color and texture because they are the basic qualities that influence consumer acceptance. Han et al. [19] reported that replacement of wheat flour with potato peels in different proportions (10%, 15% and 20%) led to a decrease in a degree of biscuit hardness in all studies samples. Cohesiveness, springiness and brittleness increased in the samples with the 10% replacement rate and decreased is all other samples compared to the control. Sensory evaluation showed that the highest scores for flavor, taste, appearance, texture and overall acceptability were in the biscuits with 10% of potato peel powder compared to the control and other samples. The scores for color were the same in the samples with the 10% replacement rate and the control. Rowayshed et al. [7] showed that an increase in the proportion of potato peel extracts in biscuits from 0.5% to 3% led to a decrease in the sensory scores for color, odor, taste, texture and overall quality compared to the control samples.

Table 5. **Effect of replacing wheat flour with different percentages of potato peel powder on the sensory properties of the studied biscuit samples**

Таблица 5. **Влияние замены пшеничной муки различными процентами порошка картофельной кожуры на сенсорные свойства исследованных образцов печенья**

Samples	Taste	Color	Smell	Texture	Melting in the mouth	Fracture	General Acceptability
Control biscuits	4.6±0.60[a]	4.7±0.33[a]	4.4±0.24[a]	4.3±0.50[a]	4.3 ±0.31[a]	4.5±0.22[a]	4.5±0.41[a]
Biscuits with 3% PPP	3.7±0.30[b]	4.4±0.42[a]	4.1±0.34[a]	4.1±0.17[a]	4.1±0.16[a]	4±0.34[a]	4.1±0.21[a]
Biscuits with 5% PPP	3.3±0.14[b]	4±0.59[ab]	4.1±0.54[a]	4±0.26[a]	3.8±0.61[b]	4±0.30[a]	3.8±0.23[b]
Biscuits with 7% PPP	3.1±0.21[b]	3.3±0.21[c]	3.6±0.52[b]	3.7±0.51[b]	3.7±0.64[b]	3.7±0.46[b]	3.5±0.64[b]
Biscuits with 10% PPP	3±0.63[b]	3.1±0.33[c]	3.5±0.24[b]	3.7 ±0.23[b]	3.1±0.12[b]	3.5±0.21[b]	3.3±0.25[b]
Biscuits with 30% PPP	2.1±0.47[c]	2.3±0.30[d]	3±0.62[c]	3.3 ±0.36[b]	2.3±0.46[c]	3±0.42[bc]	2.7±0.32[c]
Biscuits with 50% PPP	1.8±0.54[d]	1.5±0.55[e]	2.1 ±0.62[d]	2.3 ±0.42[c]	2.2±0.24[c]	2.5±0.15[d]	2.1±0.20[cd]

The same letters within the same column indicate that there are no significant differences between the means at a confidence level ($p \leqslant 0.05$). PPP — potato peel powder.

3.6. Functional properties of potato peel powder and wheat flour

Table 6. **Functional properties of potato peel powder and wheat flour**

Таблица 6. **Функциональные свойства порошка картофельной кожуры и пшеничной муки**

Studied indicators	Wheat flour	Potato peel powder
Water absorption capacity, g/g	0.97	2.58
Oil absorption capacity, g/g	1.14	1.24
Emulsion absorption capacity, g/g	1.24	3.16

The results referred to in Table 6 show that potato peel powder had better water absorption capacity (WAC), oil absorption capacity (OAC) and emulsion absorption capacity (EAC). The WAC, OAC and EAC values were 165.98%, 8.77% and 154.84% higher, respectively, in potato peel powder than in wheat flour. The results obtained are close to what was found by Ben Jeddou et al. [38], who reported that the ability to bind water in potato peel powder of the cultivar Spunta was 3.37 g/g and the ability to bind fat was 2.07 g/g.

3.7. Texture profile analysis

Texture analysis is primarily concerned with the measurement of the mechanical properties of a product, often a food product, as they relate to its sensory properties evaluated by a human. Texture analysis is performed by applying controlled forces to the product and recording its response in the form of force, deformation, and time [54]. Texture measurements are useful for quality control, process optimization, and product development with desirable features.

Data in Table 7 present the textural parameters assessed from the texture profile analysis (TPA) test of the biscuits samples (control, 3%, 5%, 7% and 10%).

As can be seen from the table, hardness of biscuits increased with increasing potato peel powder levels from 3% to 10%. The highest value of hardness was in the sample with the 10% replacement rate. A similar trend was observed for fracturability with its highest value in the samples with the biggest proportion of potato peel powder. The increment in hardness and fracturability may be due to the addition of potato peel powder. On the contrary, a decreasing trend was observed for adhesiveness, which represents the work necessary to pull the compressing plunger away from the sample [55,56], and resilience, which shows how well a product 'fights' to regain its original position [57]. The results in Table 7 show that the biscuit sample with 10% replacement had the lowest values (0.10 mj and 0.00, respectively) of these parameters compared to the control sample (0.30 mj and 0.08, respectively). The increased fiber content contributes to hardness of biscuits influencing gluten network optimal formation and resulting in a solid compact structure [58].

Table 7. **Texture properties of biscuits samples**

Таблица 7. **Текстурные свойства образцов печенья**

Sample	Hardness (N)	Adhesiveness (mj)	Resilience	Fracturability (N)
Control	11.95	0.30	0.08	11.95
3%	15.68	0.30	0.08	14.86
5%	28.08	0.20	0.01	28.08
7%	30.70	0.10	0.00	30.70
10%	41.96	0.10	0.00	41.96

Ben Jeddou et al. [38] stated that when potato powder was utilized in place of wheat flour at replacement rates of 2–10%, the cake cohesion and hardness significantly decreased. Dhingra et al. [16] observed that when the fiber content increased from 5 to 15%, the biscuits' breaking strength increased from 1.96 kg to 3.83 kg. The water-binding properties of potato peel fiber influenced the biscuits' hardness leading to its increase. So the dough did not spread well resulting in greater breaking strength, thick and small biscuits.

3.8. Dough rheological properties

Figure 3 and Table 8 illustrate the data recorded during mixing in the Mixolab. The inclusion of potato peel powder up to 10% affected the rheological behavior of the dough during mixing. While the level of water absorption was the same in the sample with the 3% replacement rate and the control, it increased in the samples containing 5%, 7% and 10% of potato peel powder by 1.24%, 2.83% and 2.83%, respectively. Similarly, an increase of 25.25%, 246.21%, 288.28% and 510.35% was observed in dough development time in the samples with the 3%, 5%, 7% and 10% replacement rate, respectively, but stability decreased in these samples by 3.76%, 5.70%, 4.09% and 5.05%, respectively, compared to the control containing only wheat flour. Dough development time and stability value indicate the flour strength. Higher values of these parameters suggest stronger doughs [59].

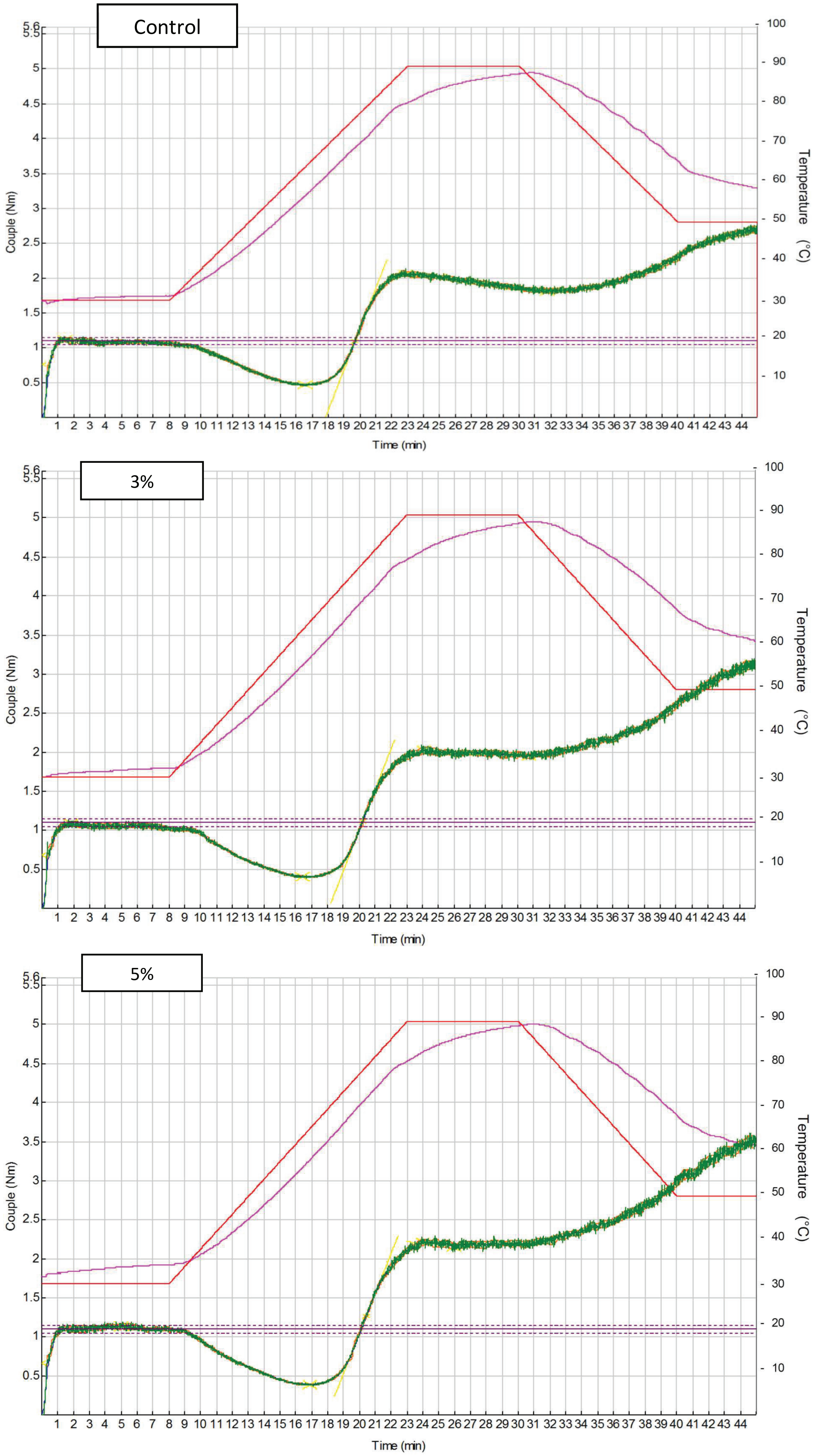
Table 8. Mixolab values of the control sample and the samples with different replacement levels (3, 5, 7, 10%)

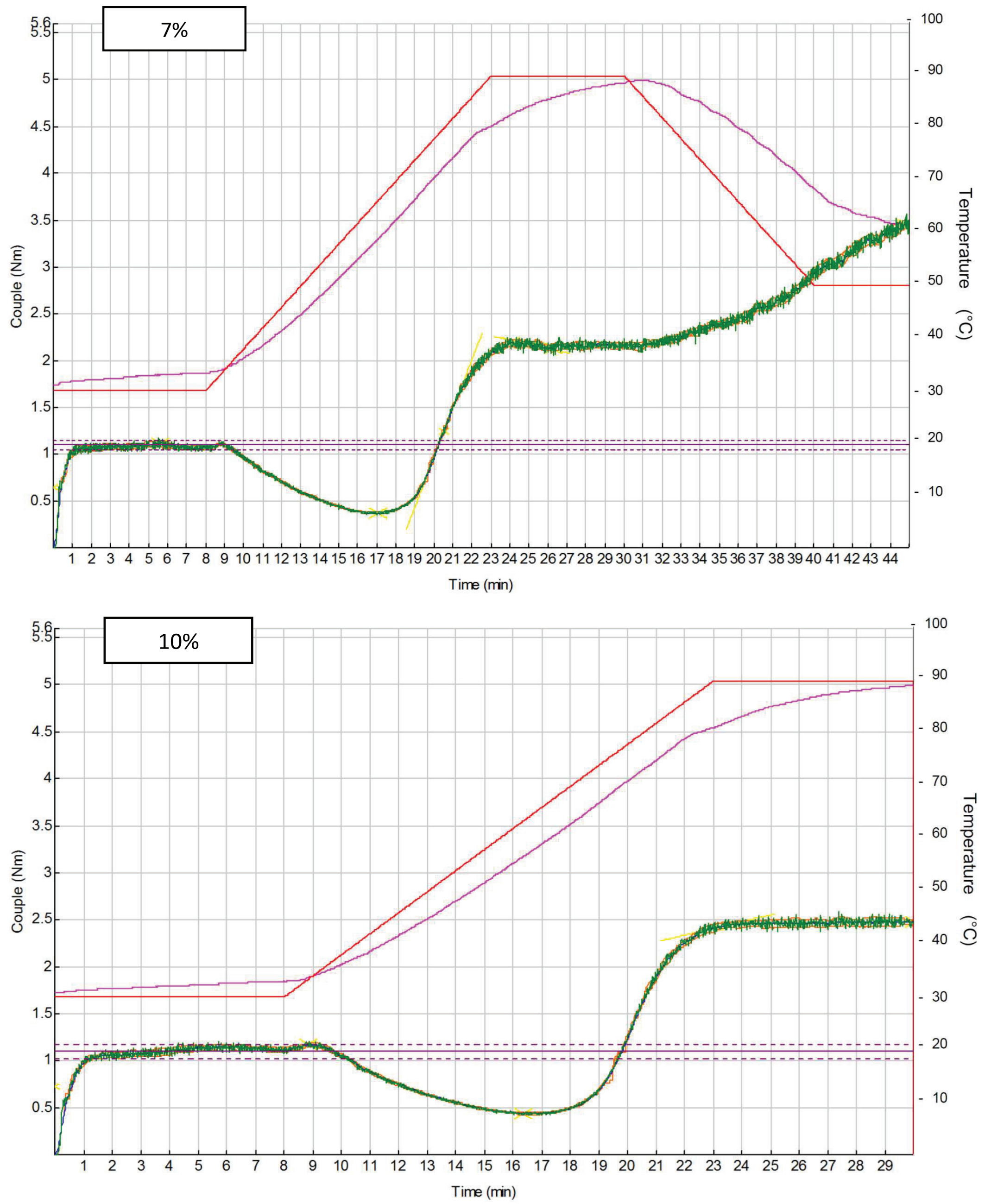
Таблица 8. **Уровни Mixolab контрольного образца и образцов с различными уровнями замены (3, 5, 7, 10%)**

Sample	Water absorption (%)	Dough development time (min)	Stability (min)
Control	56.5	1.45	9.30
3%	56.5	1. 82	8.95
5%	57.2	5.02	8.77
7%	58.1	5.63	8.92
10%	58.1	8.85	8.83

Figure 3. **Mixolab curve of the control sample and the samples with different replacement levels**

Рисунок 3. **Кривая Mixolab для контрольного образца и образцов с различными уровнями замены**





End of Figure 3. **Mixolab curve of the control sample and the samples with different replacement levels**

Окончание рисунка 3. **Кривая Mixolab для контрольного образца и образцов с различными уровнями замены**

The results obtained from alveographic measurements of dough are shown in Table 9. An increase in the proportion of potato peel powder up to 10% resulted in an increase in P (dough elasticity) compared with the control containing only wheat flour. The P values were 53.68, 54.74, 75.79, and 85.26% higher, respectively, in the samples with 3%, 5%, 7%, and 10% potato peel powder than in the control. The alveograph ratio (P/L) also increased (by 246.91, 277.78, 488.89, and 417.28%, respectively) in the dough samples with the 3%, 5%, 7%, and 10% replacement rate compared to the control. A decrease in L (dough extensibility), W (baking strength) and Le (flexibility index) was observed with an increase in the level of potato peel addition. The L value decreased by 55.56, 58.97, 70.09, 64.10%, W value by 14, 18.29, 26.86, 52.29% and Le value by 7.07, 9.54, 33.39, 74.20%, respectively, in the samples with the 3%, 5%, 7%, and 10% replacement rate compared to the control.

Table 9. **Alveographic measurement of doughs with different proportions of potato peel powder**

Таблица 9. **Альвеографические измерения теста с различными пропорциями порошка картофельной кожуры**

Parameter	Control	3%	5%	7%	10%
P (mm)*	95	146	147	167	176
L (mm)*	117	52	48	35	42
P/L*	0.81	2.81	3.06	4.77	4.19
W(10^{-4} J)*	350	301	286	256	167
Le%*	56.6	52.6	51.2	37.7	14.6

*P: dough tenacity (aptitude to resist deformation), L: dough extensibility (maximum volume of air that the bubble is able to contain), P/L: configuration of the curve, W: dough baking strength (surface under the curve), Le: Flexibility index.

Ben Jeddou et al. [38] indicated that the potato peel powder significantly improved the Alveograph profile and texture of dough, and technologically, the addition of potato peel powder at a concentration of 5% boosts the dough strength and elasticity-to-extensibility ratio (P/L). Iskander et al. [58] studied an effect of addition of alcohol insoluble residue from potato processing by-product (AIR-PPB) in wheat flour bread at different particle sizes. As the particle size increased, the results revealed an improvement in the AIR-PPB functional properties in terms of water holding capacity (WHC), swelling capacity (SC), and water solubility index (WSI). The total dietary fiber content, water absorption (WA), and dough development time (DDT) also increased with an increase in the percentage of AIR-PPB and particle size. Higher particle size gave more stability to the dough structure, but the opposite effect was exerted on dough weakening (DW) [58].

4. Conclusion

Potato peels of the Spunta variety are an important and rich source of phenolic compounds and natural antioxidants, as well as an important cheap source of protein and dietary fiber, which are important components of a healthy diet. Replacing wheat flour with different percentages of potato peel powder has contributed to making functional biscuits, reducing the economic cost and raising the nutritional value of the biscuits. Therefore, we recommend taking advantage of the secondary wastes resulting from the potato manufacturing process to obtain compounds useful in nutritional aspects instead of industrial materials, and it is proposed to develop this work in the future to obtain phenols, proteins and fibers as commercial preparations that can be used in many food industries.

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