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Research article

Enhancing quality and functionality of cookies with Saudi pumpkin peel powder

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Abstract: In this study, we aimed to enhance the nutritional and bioactive properties of cookies by utilizing pumpkin peel powder (PPP), a readily available plant waste in Saudi Arabia. Different levels of PPP (0%, 5%, 10%, 15%, and 20%) were used as a substitute for wheat flour in the cookie formulation. The effects on amylograph parameters, physicochemical characteristics, antioxidant properties, color, texture, and sensory attributes were evaluated. PPP exhibited higher levels of lipids (4.90%), ash (6.70%), and crude fiber (17.26%), along with increased redness (a* = 3.27) and yellowness (b* = 31.32) compared to wheat flour. Incorporating 5% to 20% PPP significantly increased lipids, ash, and dietary fiber in the cookies. Regarding color, increasing PPP substitution progressively decreased lightness (L* from 72.68 to 54.44) while increasing redness (a* from 0.54 to 5.10). Texture analysis revealed that PPP incorporation reduced cookie hardness from 12.54 N (control) to 9.99 N at 5% PPP and further to lower values, while fracturability increased from 2.87 mm (control) to 10.92 mm at 20% PPP, indicating improved crispness. The spread factor decreased with higher PPP

levels, from 12.65 (control) to 9.98 (20% PPP). The inclusion of PPP improved the antioxidant activity and phenolic content of the cookies, attributed to its scavenging ability (26.95%) and high total phenolic content (10.91 mg GAE/g). Sensory evaluation showed no significant difference between the control cookies and those with 5% and 10% PPP across all attributes. Cookies containing 20% PPP received an overall acceptability score of 6.2 on a 9-point hedonic scale, corresponding to "like slightly," indicating that they were acceptable to panelists, albeit with lower scores for texture, taste, and aroma compared to lower substitution levels. In conclusion, adding up to 20% PPP to cookies is sensorially acceptable and enhances their nutritional value, antioxidant activity, and textural properties, with 5–10% substitution providing the best overall consumer acceptance.

Keywords: pumpkin peel; amylograph phytochemicals; acceptability; texture; antioxidant; cookies

1. Introduction

The pumpkin, a fruit indigenous to tropical and subtropical regions, boasts an impressive nutritional profile. The pumpkin, which belongs to the Cucurbitaceae family, is commercially available in three predominant varieties: Cucurbita moschata, Cucurbita maxima, and Cucurbita pepo. The big producers in the world are USA, India, Russia, and China. Phytochemicals contained in pumpkin fruits include vitamins, polyphenols, carotenoids, minerals, pectin, fiber, tocopherols, essential oils, amino acids, and proteins [1]. The pumpkin, in addition to being a rich source of carbohydrates and other constituents with significant nutritional value and biological activity, also contains a large amount of calcium, phosphorus, vitamin A, and B complex vitamins. Pumpkin peel, while not a substantial source of carbohydrates, potassium, lipids, or iron, is notably rich in protein and dietary fiber; in addition to ascorbic acid and calcium, these are present in relatively lower concentrations when compared to the commonly utilized pulp portions of the plant [2]. Therefore, using pumpkin peels in flour production can improve nutrient utilization. It contains natural pigments that determine the appearance, color, and taste of foods made from pumpkin. The incorporation of pumpkin into developed foods serves to augment their nutritional value. Due to its beneficial nutraceutical characteristics and functional food properties, pumpkin is recognized as a highly versatile food ingredient [3]. The transformation of agricultural waste into valuable food resources is a burgeoning field of interest within industry. By-products of pumpkin processing, including peels and seeds, are abundant in advantageous nutrients [4]. It is a remarkable reservoir of polysaccharides, pectins, and carotenoids, while the seeds are abundant in bioactive compounds. The byproducts of pumpkin processing can contribute to health directly and through the generation of nutrient-rich food. The peel, pulp, and seeds of the pumpkin are dehydrated to yield superior quality powder. Subsequent analysis reveals that these three components of the pumpkin are rich in phytochemicals that promote health [5]. Pumpkin has garnered considerable attention in the development of value-added foods and nutraceuticals, owing to its potential antidiabetic and anticancer properties. Pumpkin fruit can serve as a source of bioactive substances that promote human health [6]. The necessity to transform waste streams from pumpkin processing into beneficial powders is paramount. These pumpkin-derived powders can then be utilized to produce palatable baked goods, while ensuring minimal loss of quality. Moreover, pumpkin parts powder can replace wheat flour in different substitution amounts, reducing the economic burden of wheat flour consumption [7]. By incorporating powder derived from pumpkin parts into the flour blend, the

efficiency of the procedure and the quality of the baked products can be enhanced to fulfill the requisite standards.

Cookies are a variety of biscuits, crafted from a soft, crumbly dough that exhibits a less dense texture upon fracturing. Biscuits, on the other hand, are dry baked goods, composed of dough made from wheat flour. This dough may be prepared with or without the inclusion of substitutes and fats, and may incorporate other food ingredients and approved food additives. Biscuits are widely consumed by young children and the elderly. Several studies in Semarang have shown that biscuits are the most consumed food by children after milk [8]. It appears that cookies are an optimal choice for the integration of innovative ingredients. They possess a triad of appealing characteristics: cost-effectiveness, enhanced longevity, and a wide-ranging appeal that transcends age groups [9]. The annual global consumption has reached an astounding volume of 10 million tons, so biscuits present a substantial opportunity for the food industry to incorporate innovative nutritional components.

The escalating demand for health-conscious products with functional attributes has spurred the food industry to investigate the incorporation of non-traditional flours in biscuit production. Whole wheat flour has emerged as a favored option due to its superior fiber content and additional nutrient profile[10,11]. Nevertheless, researchers have ventured beyond conventional cereals and probed into the potential of flours derived from legumes [12]. The objective of this research was to evaluate the feasibility of utilizing locally sourced Saudi Arabian pumpkin peel powder (PPP) as a functional ingredient in cookie formulation. While studies from South Asian countries have investigated pumpkin peel-enriched bakery products [13,14], several methodological gaps remain unaddressed. These include: (i) The absence of amylograph analysis to examine gelatinization behavior of PPP-fortified wheat flour doughs; (ii) lack of instrumental texture parameters (hardness and fracturability) for PPP-enriched cookies; and (iii) no comprehensive functional property characterization (water holding capacity, oil holding capacity, bulk density, and swelling index) for Saudi Arabian pumpkin peel powder. We therefore aim to: (1) Characterize the physicochemical, functional, and antioxidant properties of locally sourced PPP; (2) evaluate the amylograph parameters of wheat flour-PPP suspensions; (3) assess the instrumental texture, color, and sensory properties of cookies formulated with 0–20% PPP substitution; and (4) establish dose–response relationships between PPP level and antioxidant activity. By addressing these gaps, this study provides region-specific data for Saudi Arabia while contributing novel methodological insights to the broader field of pumpkin by-product valorization in bakery applications.

2. Materials and methods

2.1. Materials

Pumpkin fruit (*Cucurbita maxima L.*), soft wheat flour with a 70% extraction rate, skimmed milk powder, shortening, sugar, and salt were procured from a market in Qassim Region, Saudi Arabia. Ammonium bicarbonate, sodium bicarbonate, and food grade dextrose were used in cookie production. Additionally, 1,1-diphenyl-2-picrylhydrazyl radical (DPPH), sodium carbonate, Folin-Ciocalteus phenol reagent, and methanol were procured from Sigma–Aldrich Inc. (St Louis, MO, USA).

2.2. Methods

2.2.1. Formulation of pumpkin peel powder

The preparation of Pumpkin Peel Powder (PPP) (Figure 1) was conducted in accordance with the methodology outlined by Hussain et al. [7]. Fresh pumpkin was thoroughly rinsed under running water, peeled with a knife, and subsequently dried in a hot air oven at 60 °C until a uniform moisture content was reached. The dried pumpkin peel was then ground using a grinder (NIMA NM-8300 Japan) to obtain powders with a particle size smaller than 0.2 mm. PPP was preserved in a sealed bottle at 4 °C until it was ready for use and analysis.



Figure 1. Visual appearance of fresh, dried and powdered pumpkin peels (PPP).

2.2.2. Evaluation of the functional characteristics of wheat flour and PPP

Water Holding Capacity (WHC) and Oil Holding Capacity (OHC): These parameters were quantified following the methodology described by Rodríguez- Ambriz et al. [15]. A 1 g sample of wheat flour or PPP was placed in a pre-weighed centrifuge tube. Subsequently, 25 mL of distilled water (for WHC) or 25 mL of olive oil (for OHC) was added. The mixture was stirred vigorously for 1 minute using a vortex mixer to ensure complete dispersion. The tubes were then incubated at 60 °C for 1 hour in a temperature-controlled water bath. After incubation, the tubes were centrifuged at 3000×g for 20 minutes at room temperature using a refrigerated centrifuge (Model 5810 R, Eppendorf, Germany). The supernatant was carefully decanted, and the tubes were inverted and placed at a 45° angle on absorbent paper for 10 minutes to allow drainage of any residual liquid. The tubes were then weighed, and the residue mass was calculated by subtracting the initial tube weight. WHC and OHC were expressed as grams of water or oil retained per gram of dry sample (g/g).

Bulk Density (BD): Bulk density was determined according to the method described by Kaur M et al. [16]. with minor modifications. A 10 g sample of wheat flour or PPP was gently poured into a 100 mL graduated glass cylinder without tapping or vibration. The initial volume occupied by the powder was recorded immediately after pouring (V0). The cylinder was then tapped manually on a rubber mat from a height of 2 cm at a rate of 10 taps per minute until no further reduction in volume was observed (typically 100 taps). The final volume (Vf) was recorded. Bulk density was calculated using the following formula:

Bulk Density (g/cm^3) = Mass of sample (g) Final volume after tapping (mL) Bulk Density (g/cm^3) = Final volume after tapping (mL) Mass of sample (g) (1)

All measurements were performed in triplicate, and the results were expressed as mean ± standard error.

Swelling Index (SI): The swelling index was determined following the procedure of [17] with slight modifications. A 1 g sample of wheat flour or PPP (dry weight) was placed in a 15 mL graduated centrifuge tube. The tube was filled to the 10 mL mark with distilled water. The mixture was stirred with a glass rod for 30 seconds to eliminate air bubbles and ensure uniform hydration. The tube was then allowed to stand at room temperature (25 ± 2 °C) for 24 hours without disturbance. After 24 hours, the volume of the swollen sediment (swollen sample volume) was read directly from the graduated scale of the tube. The swelling index was calculated using the following equation:

Swelling Index (mL/g) = Volume occupied by the swollen sample (mL) Dry weight of sample (g) Swelling Index (mL/g) = Dry weight of sample (g) Volume occupied by the swollen sample (mL) (2)

Triplicate determinations were performed for each sample, and results were reported as mean ± standard error.

2.2.3. Rheological properties of wheat flour-PPP suspensions

The amylograph parameters of wheat flour and wheat flour integrated with varying levels of (PPP) were examined using a Brabender Amylograph (OHG Duisburg Kulturstra Be 51-55, D-4100 Duisburg, Germany), in compliance with the methodology outlined in reference [18]. The results obtained from the amylograms curves were the beginning of gelatinization (°C), gelatinization temperature (°C), and gelatinization maximum (AU).

2.2.4. Preparation of cookies containing PPP

The control cookies, composed entirely of wheat flour, were prepared following the methodology outlined in reference [19], and cookie formulations incorporating 5%, 10%, 15%, and 20% of (PPP) as a substitute for wheat flour were examined. A quantity of (100 g) wheat flour and (1.5 g) of baking powder were blended using a commercial sigma blender for a duration of 8 minutes at a medium speed. Concurrently, a homogeneous paste was prepared in a stainless-steel pan, consisting of (25 g) of fat and (35 g) of sugar. This paste was then meticulously combined with the dry mix at a high speed in the blender to achieve a uniform dough. The resultant dough was then rolled to a consistent thickness of 6 mm and subsequently shaped into round cookies using a cutter. Then, cookies were subjected to a baking process at a temperature setting of 175 °C for a time span of 15 minutes, subsequently cooled to room temperature, and then securely packaged in airtight polythene bags. The samples were preserved at a steady room temperature (23 °C) until further examination was conducted.

2.2.5. Approximate chemical composition

Samples of wheat flour, PPP, and prepared cookies were subjected to analysis for parameters such as moisture content, crude fiber, ash, crude protein, and lipids, employing the methodologies delineated in [20]. This was done to ensure a comprehensive understanding of their nutritional

composition. The quantification of moisture content was accomplished utilizing oven drying techniques. The determination of nitrogen content was conducted using the micro-Kjeldahl method. Subsequently, the conversion to protein content was achieved by applying a multiplication factor of 5.70 for wheat flour and 6.25 for PPP and cookie samples. The carbohydrate content, also referred to as Nitrogen-Free Extract (NFE), was computed by difference.

2.2.6. Evaluation of phenolic content and antioxidant activity (DPPH) assay

Extraction procedure: Extraction was performed in triplicate for each sample according to the method of Bloor [21] with modifications. A 0.5 g sample of pumpkin peel powder (PPP) or cookie (ground to pass a 0.5 mm sieve) was placed in a 50 mL glass centrifuge tube. Twenty milliliters of methanol:water (60:40 v/v) were added, and the mixture was vortexed for 30 seconds. The tubes were then placed in a temperature-controlled shaking water bath (Model SWB-25, J.P. Selecta, Barcelona, Spain) set at 60 °C for 30 minutes with continuous shaking at 150 rpm. After extraction, the tubes were cooled to room temperature (25 ± 2 °C) and centrifuged at 4000×g for 15 minutes at 4 °C using a refrigerated centrifuge (Model 5810 R, Eppendorf, Hamburg, Germany). The supernatant was carefully decanted and filtered through Whatman No. 1 filter paper into a 25 mL volumetric flask, and the volume was adjusted to 25 mL with extraction solvent. The extracts were stored at 4 °C in amber glass vials until analysis (within 24 hours). All extractions were performed in triplicate.

Total phenolic content: Total phenolics were determined using the Folin-Ciocalteu method as described by Vl S [22]. An aliquot of 0.5 mL of the extract was transferred to a 15 mL test tube, followed by 2.5 mL of 0.2 N Folin-Ciocalteu reagent (diluted 1:10 with distilled water). The mixture was vortexed and allowed to stand for 5 minutes at room temperature. Then, 2.0 mL of 7.5% sodium carbonate (Na_2CO_3) solution was added, and the mixture was vortexed again. The tubes were incubated in the dark at room temperature for 60 minutes. Absorbance was measured at 765 nm using a UV-Vis spectrophotometer (Model UV-1800, Shimadzu Corporation, Kyoto, Japan). A calibration curve was prepared using gallic acid standards (0–200 mg/L). Results were expressed as milligrams of gallic acid equivalent per gram of dry sample (mg GAE/g). All measurements were performed in triplicate.

DPPH radical scavenging activity: The DPPH scavenging activity was determined according to Blois [23] and *Ghendov-Mosanu et al.* [24] with modifications. A 0.1 mM DPPH solution was prepared in methanol. An aliquot of 1.0 mL of the sample extract was mixed with 3.0 mL of DPPH solution in a glass cuvette. The mixture was vortexed and incubated in the dark at room temperature for 30 minutes. Absorbance was measured at 517 nm against a methanol blank. A control sample (1.0 mL methanol + 3.0 mL DPPH solution) was prepared and measured similarly. All measurements were performed in triplicate. Scavenging activity was calculated using the following equation:

$$\text{Scavenging activity (\%)} = [(\text{Abs_control} - \text{Abs_sample}) / \text{Abs_control}] \times 100 \quad (3)$$

where Abs_control is the absorbance of the DPPH solution without extract, and Abs_sample is the absorbance of the DPPH solution with extract.

2.2.7. Physical measurements of cookies

The physical parameters were quantified utilizing the methodology delineated in reference [18]. The diameter (W) of the cookies, expressed in millimeters, was ascertained by aligning six pieces

edge-to-edge and measuring the total length with a scale. The reported values represent the average measurements. The thickness (T) of the cookies, also in millimeters, was determined by stacking six pieces above one another and measuring the total height. The average thickness was then calculated. The spread ratio was computed by dividing the diameter (W) by the thickness (T).

2.2.8. Color measurements of cookies

The color attributes of wheat flour, PPP, and cookies were measured using the CIE L*a*b* tristimulus color system. Measurements were performed using a Hunter Lab ColorFlex spectrophotometer (Model 45/0, Hunter Associates Laboratory, Reston, VA, USA) calibrated against a standard white tile (L* = 93.5, a* = -0.9, b* = 1.2). The instrument was set to illuminant D65 and a 10° observer angle. Samples (approximately 10 g) were placed in a glass petri dish (5 cm diameter), pressed flat, and measured at three random positions per sample. The parameters recorded were L* (lightness, 0 = black, 100 = white), a* (redness positive, greenness negative), and b* (yellowness positive, blueness negative). Results are expressed as mean ± standard error (n = 6). This method is widely used for color evaluation of cereal and bakery products by Pathare et al. [25] ,Wrolstad et al. [26], and Francis [27]. This assessment was conducted using the Hunter Lab Color QUEST II Minolta CR-400 instrument (Japan). The measurements included L values (ranging from 100 for white to 0 for black), a value (positive for red and negative for green), and b values (positive for yellow and negative for blue).

2.2.9. Texture analysis of cookies incorporated with PPP

The texture of the cookie samples was quantitatively assessed using an instrumental technique as outlined in reference [28]. A Texture Analyzer from Stable Micro System, Godalming, UK, equipped with a 5.0 kg load cell and a 2 mm cylindrical probe (P/2), was employed to conduct a penetration test. The parameters for the test were set as follows: A pre-test speed of 1.0 mm/s, a test speed of 0.5 mm/s, a post-test speed of 10.0 m/s, a distance of 5 mm, and a trigger force of 50 g. The hardness was ascertained from the maximum peak force (N), while the fracturability was determined from the distance (mm) at which the cookies fractured.

2.2.10. Sensory evaluation of cookies

Control cookies, along with cookie samples incorporating PPP at concentrations of 5%, 10%, 15%, and 20%, were subjected to sensory evaluation. Twenty trained panelists (10 male, 10 female; aged 30–50 years) from the Department of Food Science and Human Nutrition at Qassim University volunteered and gave informed consent. Cookie samples (5 g each) were served in white cups labeled with three-digit codes at room temperature and presented in random order. Unsalted crackers and filtered water were provided for palate cleansing. Panelists were instructed to rinse their mouths with water before and between samples, evaluate appearance and color first, then texture by hand, followed by aroma, taste, and overall acceptability using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). A 30-second break was taken between samples, and communication was not allowed [29].

2.2.11. Statistical analysis

The statistical evaluation was performed using SAS software (version 9.4, SAS Institute Inc., Cary, NC, USA). Data were expressed as mean ± standard error (SE). One-way analysis of variance (ANOVA) was applied to determine significant differences among treatment means. When ANOVA indicated a significant effect ($p \leq 0.05$), post-hoc multiple comparisons were conducted using Duncan's multiple range test (Duncan, Steel et al., Gacula. A significance level of $p \leq 0.05$ was adopted for all statistical tests [30–32].

3. Results and discussion

3.1. Functional characteristics of wheat flour and PPP

Functional characteristics of wheat flour and (PPP) were evaluated and the results are presented in Table 1. The ability to absorb water is a crucial characteristic of PPP, which potentially augments its suitability as a thickening agent in the stabilization of liquid or semi-liquid food products [13,14,33]. This property broadens the scope of its application in the food industry. The results indicated that there exist statistically significant variances ($P < 0.05$) in the capacity to retain water between wheat flour and PPP. Specifically, PPP exhibited the highest value of (11.46 g/g), while wheat flour registered the lowest value at (3.15 g/g). Pumpkin peels are characterized by a substantial proportion of insoluble fiber constituents, including cellulose, hemi-cellulose, pectin, and lignin [13]. These components exhibit a pronounced propensity for water absorption. The Water Absorption Index is a vital processing parameter with substantial implications for viscosity. It plays an indispensable role in imparting bulk and consistency to products, as indicated in [34].

Regarding oil holding capacity (OHC), PPP exhibited a slightly but significantly higher value (1.90 g/g) than wheat flour (1.79 g/g). This difference can be attributed to the higher crude fiber content of PPP (17.26%) compared to wheat flour (0.50%). Dietary fiber, particularly insoluble fractions such as cellulose, hemicellulose, and lignin, possesses a porous structure and hydrophobic surface regions that facilitate the physical entrapment and adsorption of oil molecules. Additionally, the higher protein content of PPP (11.10% vs. 10.90%) may contribute to oil binding, as proteins have hydrophilic and hydrophobic amino acid residues that can interact with lipid phases.

The oil absorption index is a critical parameter as it contributes to the enhancement of flavor and the mouthfeel of foods, thereby improving their palatability and extending their shelf life. This is particularly relevant in the case of bakery and meat products where the inclusion of fat is a necessity [35].

It was observed that for the bulk density (BD), wheat flour demonstrated a significantly higher value (0.64 g/cm³) than PPP (0.40 g/cm³). This disparity is primarily due to differences in particle size, shape, and chemical composition. Wheat flour consists predominantly of starch granules with a relatively compact, uniform structure, leading to tighter packing and higher density. In contrast, PPP contains a high proportion of dietary fiber (17.26%) with irregular, fibrous, and porous particles that do not pack as efficiently, resulting in increased void volume and lower bulk density. Furthermore, the lower starch content of PPP (60.04% NFE vs. 85.43% in wheat flour) reduces the overall mass per unit volume.

Furthermore, no significant differences ($P < 0.05$) were detected in the swelling index (SI) between wheat flour and PPP, with values of 6.83 and 7.33, respectively. The researchers in [36]

confirmed that pumpkin peels contain a high percentage of dietary fiber, which is the reason for their high ability to bind water, while a significant amount of oil retention did not appear within the pumpkin peel powder. Pumpkin flour exhibits a commendable capacity for oil binding and water absorption. Furthermore, its properties render it an apt substitute for conventional emulsifiers, thereby extending its potential use in various food mixtures [37].

Table 1. The functional characteristics of wheat flour and pumpkin peel powder (PPP).

Materials	WHC (g/g)	OHC (g/g)	BD (g/cm^3)	SI
Wheat flour	$3.15^{b} \pm 0.34$	$1.79^{b} \pm 0.03$	$0.64^{a} \pm 0.05$	$6.83^{a} \pm 0.66$
PPP	$11.46^{a} \pm 0.19$	$1.90^{a} \pm 0.28$	$0.40^{b} \pm 0.02$	$7.33^{a} \pm 0.66$

The data presented are the mean ± standard error (SE), with a sample size of 3. Values in the same column that are denoted by identical letters do not exhibit significant differences ($P \leq 0.05$). PPP: pumpkin peel powder; OHC: oil holding capacity; BD: bulk density; SI: swelling index.

3.2. Physicochemical of wheat flour and pumpkin peel powder

Proximate chemical analysis, color, and antioxidant properties of wheat flour and PPP were evaluated, with the results presented in Table 2. It was observed that PPP exhibited a higher moisture content 12.59% compared to wheat flour, which recorded 11.27% with significant difference ($P < 0.05$), which are below the moisture critical limit for storage (14%). Regarding total protein, no significant ($P < 0.05$) difference was noticed between wheat flour 10.90% and PPP 11.10%. PPP demonstrated a statistically significant ($P < 0.05$) augmentation in the levels of total lipids, ash, and crude fiber, registering at 4.90%, 6.370%, and 17.26% respectively, when juxtaposed with wheat flour. These findings are in alignment with the results in [38], who stated that the lipid and protein content in pumpkin peel flour surpasses the corresponding values found in wheat flour. On the other hand, wheat flour had a higher amount of carbohydrates (NFN), at 85.43%, with a significant ($P < 0.05$) difference than those recorded by PPP, which had a carbohydrate content of 60.04%. The researchers in [39] found that NDF and ADF content ranged between 15.5 to 26.5% and 10.12 to 24.65%, respectively, of dry weight in the 10 pumpkin cultivars.

It is acknowledged that a significant color disparity exists between wheat flour and PPP. The wheat flour exhibits a bright white hue, whereas the PPP is characterized by a distinct yellow color. Thus, our results showed that the wheat flour had a significant ($P < 0.05$) increase in Lightness (L^*), at 87.95, compared to PPP, which recorded 61.66. While PPP showed a significant ($P < 0.05$) increase with a high value of Redness (a^*) and Yellowness (b^*), being 3.27 and 31.32, respectively, compared to wheat flour. Staichok et al. [38] indicated that the Pumpkin Peel Flour exhibited a lightness (L*) value approximating the value associated with white, an (a*) value nearing green, and a (b*) value trending toward yellow.

Consistent with other reports, pumpkin peels are recognized as a valuable source of phenolic substances and bioactive compounds. Our results revealed that PPP had a high significant ($P < 0.05$) increase in total phenolics and antioxidant activity, at 10.91 mg GAE/g and 26.95%, respectively, when compared to wheat flour. The researchers in [24] found that pumpkin powder is a potent source of bioactive compounds, including polyphenols, flavonoids, and carotenoids, exhibiting substantial antioxidant potential.

The higher lightness (L* = 87.95) of wheat flour compared to PPP (L* = 61.66) is attributed to the absence of colored pigments in refined wheat flour, which consists primarily of starch and protein with a white to off-white appearance. In contrast, PPP contains carotenoid pigments (particularly β-carotene and lutein), chlorophyll derivatives, and other flavonoids that impart a darker, yellow-orange hue, thereby reducing reflected light and lowering L* values.

The significantly higher redness (a* = 3.27) and yellowness (b* = 31.32) values observed in PPP are directly attributable to its rich carotenoid profile. Pumpkin peels are known to accumulate high concentrations of β-carotene (providing orange-yellow color), α-carotene, lutein, and zeaxanthin. These lipophilic pigments are concentrated in the peel tissue as a protective mechanism against oxidative stress and UV radiation. The positive a* value indicates a shift toward the red-green axis, likely due to the presence of lycopene and other red-toned carotenoids, while the high b* value reflects the dominance of yellow-orange carotenoids. Similar findings have been reported in [38], notinh that pumpkin peel flour exhibits lower lightness and higher redness and yellowness compared to wheat flour.

Similar findings were observed in [40], where L* values diminished, and the a* and b* values escalated with an increase in the level of PPP incorporation in the biscuit. The elevated content of colored pigments in PPP may account for the decrease in L* values.

Table 2. Proximate composition, color parameters, total phenolic content, and DPPH scavenging activity of wheat flour and pumpkin peel powder (PPP).

Parameter	Wheat flour	PPP
Moisture content (%)	$11.27^{b} \pm 0.08$	$12.58^{a} \pm 0.02$
Crude protein (%)	$10.90^{a} \pm 0.21$	$11.10^{a} \pm 0.06$
Lipids (%)	$1.80^{b} \pm 0.06$	$4.90^{a} \pm 0.06$
Ash (%)	$1.37^{b} \pm 0.09$	$6.70^{a} \pm 0.51$
Crude fiber (%)	$0.50^{b} \pm 0.06$	$17.26^{a} \pm 0.26$
NFE* (%)	$85.43^{a} \pm 0.17$	$60.04^{b} \pm 0.39$
Lightness (L*)	$87.95^{a} \pm 0.50$	$61.66^{b} \pm 0.21$
Redness (a*)	$-0.34^{b} \pm 0.14$	$3.27^{a} \pm 0.08$
Yellowness (b*)	$9.31^{b} \pm 0.05$	$31.32^{a} \pm 0.13$
Total phenolic (mg GAE/g)	$1.15^{b} \pm 0.25$	$10.91^{a} \pm 0.74$
Scavenging activity (%)	$2.65^{b} \pm 0.64$	$26.95^{a} \pm 0.93$

The data presented are the mean ± standard error (SE), with a sample size of 3. Values in the same row that are denoted by identical letters do not exhibit significant differences ($P \leq 0.05$). The NFE* is calculated by differences. PPP: pumpkin peel powder.

3.3. Amylograph parameters for wheat flour suspension with different ratio of PPP

Figures 2 and 3 illustrate the results of the amylograph test for wheat flour suspensions containing different levels of PPP. The findings indicated that the onset temperature of gelatinization decreased marginally from 58.8 °C (control wheat flour) to 57.9 °C and 57.8 °C for suspensions containing 5% and 20% PPP, respectively. This slight reduction can be explained by the high content of dietary fiber (17.26%) and low starch content in PPP. Dietary fibers interfere with the ordered packing of starch granules within the flour matrix, creating physical discontinuities that enable water to penetrate more

readily and initiate gelatinization at a slightly lower temperature. Additionally, the presence of soluble fibers and small sugars in PPP may act as plasticizers, lowering the energy required for granular swelling.

Likewise, the gelatinization temperature (peak viscosity temperature) decreased progressively with increasing PPP substitution, from 90.2 °C (5% PPP) to 76.8 °C (20% PPP). This marked decline is attributed to the dilution of starch by PPP, which reduces the overall starch concentration available for gelatinization. Moreover, the high fiber content in PPP competes with starch for water absorption, altering the hydrothermal environment and shifting the gelatinization profile to lower temperatures. Similar effects have been reported for other fiber-rich additives in wheat flour systems.

Concerning the maximum gelatinization (peak viscosity), a pronounced decrease was observed as the PPP replacement ratio increased. The control wheat flour exhibited a peak viscosity of 1756 AU, whereas suspensions containing 5% to 20% PPP showed progressively lower values ranging from 929 AU down to 888 AU. This reduction is primarily due to two factors: (1) The partial replacement of starch-rich wheat flour with PPP, which contains only 60.04% nitrogen-free extract (mostly non-starch carbohydrates) compared to 85.43% in wheat flour, thereby reducing the total starch content available for viscosity development; and (2) the high dietary fiber content of PPP (17.26%) physically interferes with the swelling and pasting of starch granules by restricting water availability and disrupting the continuous starch network. The fibers also adsorb water, further limiting hydration of the remaining starch. These observations are consistent with Imran Pasha IP et al. [41], who reported a proportional increase in water absorption but a decrease in viscosity with rising levels of pumpkin flour in composite doughs.

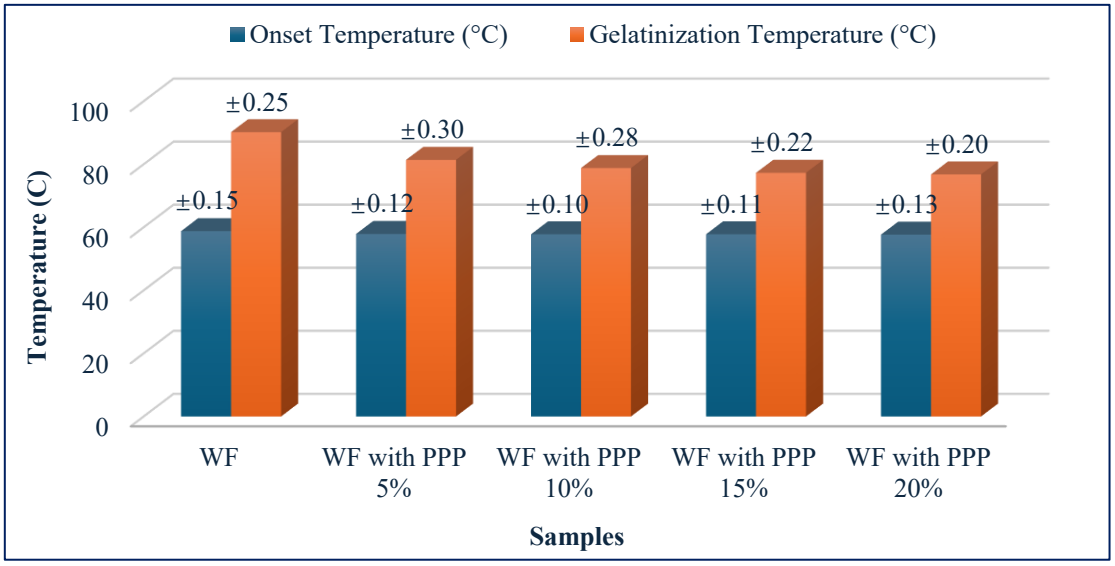


Figure 2. Effect of pumpkin peel powder (PPP) on the onset and gelatinization temperatures of wheat flour suspensions. Data are presented as mean ± SE (n = 3). Different superscript letters for each parameter indicate significant differences ($P \leq 0.05$). WF: wheat flour.

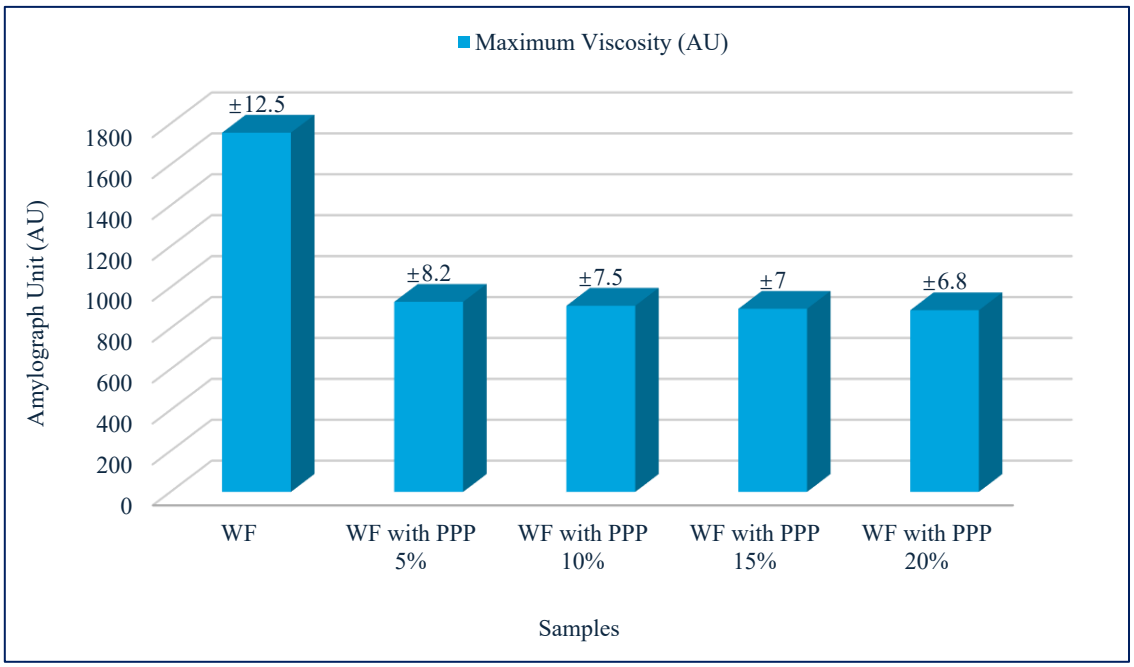


Figure 3. Effect of pumpkin peel powder (PPP) on the maximum gelatinization viscosity (AU) of wheat flour suspensions. Data are presented as mean ± SE (n=3). Different superscript letters indicate significant differences ($P \leq 0.05$).

3.4. Chemical composition of cookies fortified with different levels of PPP

The proximate composition of cookie samples, which incorporated varying ratios of PPP, was examined, and the resulting data are presented in Table 3. It was observed that there was no significant ($P < 0.05$) difference in the moisture content between the control cookies and the formulated cookies, as moisture ranged from 5.55% for the control sample to 6.23%, which was found in cookies with 20% PPP. The data indicated that the incorporation of PPP in cookie production led to a small but statistically significant ($P < 0.05$) reduction in crude protein content, which varied from 8.80% for the control sample to 6.87% for cookies with a 20% PPP inclusion. It could be mentioned that with increased amounts of PPP in cookies from 5 to 20%, lipids, ash, and dietary fiber significantly ($P < 0.05$) increased. The lowest value of lipids, 20.00%, was recorded for the control cookies, while the highest were 21.70 and 22.55% for cookies containing PPP at 15 and 20%, respectively. Researchers have found that the dietary fiber and crude fiber protects against disease [42]. As shown in Table 2, PPP is rich in crude fiber (17.26%) and ash (6.70%). The significant increase in ash content of cookies with higher PPP substitution (from 1.07% in control to 1.47% in 20% PPP) is directly related to the mineral content associated with dietary fiber. Pumpkin peels contain substantial amounts of insoluble fiber components (cellulose, hemicellulose, and lignin) that inherently carry bound minerals such as potassium, calcium, magnesium, and phosphorus. These minerals are not easily separated from the fiber matrix during processing. Therefore, as PPP substitution increases, crude fiber and ash content rise proportionally because the fiber fraction serves as a carrier for mineral elements. This positive correlation between dietary fiber and ash content has been well documented for fruit and vegetable by-products, where fiber-rich fractions consistently exhibit higher mineral content compared to refined flours. Consequently, PPP-enriched cookies not only provide more dietary fiber but also contribute

essential dietary minerals. Moreover, cookies fortified with 20% of PPP had higher fiber content 2.93% with a significant ($P < 0.05$) increase followed by 2.36 and 1.80% for cookies with 15 and 10% PPP, respectively, as compared to the control cookies. The researchers in [43] found that the fiber content was least in the controlled cookies 2.7% but was increased by incorporating pumpkin flour.

As a result of previous findings, it was discerned that there was no statistically significant ($P < 0.05$) disparity in the carbohydrate content (NFE) between the control cookies and the cookies formulated with 5% and 10% PPP, which recorded the highest values 69.21, 69.37, and 68.79%, respectively. These results agreed with [44] and [45], reporting that the pumpkin biscuit was high in protein, ash, and fiber, and the lowest in moisture and carbohydrate due to the nutritional value of pumpkin powder.

Table 3. Proximate composition (% on dry weight basis) of cookies incorporated with PPP.

Treatments	Moisture	Crude protein	Lipids	Ash	Crude fiber	NFE*
Control cookies	5.55^{a}±0.48	8.80^{a}±0.12	20.00^{c} ±0.58	1.07^{b} ±0.07	0.93^{d}±0.02	69.21^{a}±0.63
Cookies with PPP 5%	6.03^{a}±0.15	7.40^{b}±0.06	20.79^{bc} ±0.12	1.10^{b} ±0.06	1.33^{d}±0.20	69.37^{a}±0.37
Cookies with PPP 10%	5.88^{a}±0.32	7.10^{c}±0.06	21.10^{b} ±0.19	1.20^{ab} ±0.06	1.80^{c}±0.15	68.79^{ab}±0.32
Cookies with PPP 15%	5.77^{a}±0.26	6.93^{c}±0.09	21.70^{ab}±0.12	1.30^{ab} ±0.06	2.36^{b}±0.15	67.70^{b}±0.18
Cookies with PPP 20%	6.23^{a}±0.41	6.87^{c}±0.12	22.55^{a} ±0.13	1.47^{a} ±0.15	2.93^{a}±0.09	66.18^{c}±0.32

PPP refers to Pumpkin Peel Powder. The data presented are the mean ± standard error (SE), with a sample size of 3. Values in the same column that are denoted by identical letters do not exhibit significant differences ($P \leq 0.05$). The NFE* is calculated by differences.

The progressive increase in fat content of cookies with rising PPP substitution levels (from 20.00% in control to 22.55% in 20% PPP) is primarily explained by the inherent lipid composition of the raw materials. As shown in Table 2, PPP contains 4.90% lipids, whereas wheat flour contains only 1.80%. Consequently, partial replacement of wheat flour with PPP introduces additional lipids into the cookie formulation. This effect is cumulative; higher substitution levels result in greater incorporation of pumpkin peel lipids, which are naturally present in the peel tissue, including phospholipids, glycolipids, and neutral lipids associated with cell membranes and cuticular waxes. Additionally, the high dietary fiber content of PPP (17.26%) may physically entrap and retain added fat (shortening) during dough mixing, further contributing to the measured fat content. A similar trend has been reported by other researchers who observed increased lipid content in baked products fortified with pumpkin peel or seed powders [38,45].

3.5. Physical properties of cookies incorporated with PPP

Table 4 delineates the impact of substituting wheat flour with PPP at proportions of 5%, 10%, 15%, and 20% on the physical attributes of the resultant cookies. It is evident that an escalated proportion of PPP in the cookies corresponded to a statistically significant ($P < 0.05$) increase in the weight of the cookies, relative to the control sample. Cookies containing 20 and 15% of PPP recorded the highest weights of 14.82 and 14.27 grams, respectively, while control cookies had the lowest weight at 12.87 grams. Concerning diameters of the cookies, no significant ($P < 0.05$) difference was found between control and cookies with 5 and 10%, showing 57.33, 54.33, and 54.00 mm, respectively.

Data also revealed that adding PPP to cookies did not affect their thickness, which ranged from 4.53 mm for the control sample to 5.03 mm for cookies with 20% PPP.

The spread ratio (diameter/thickness) decreased progressively with increasing PPP substitution. Control cookies exhibited the highest spread ratio (12.65). Cookies containing 5%, 10%, 15%, and 20% PPP showed spread ratios of 11.44, 11.02, 10.63, and 9.98, respectively. The reduction became more pronounced at substitution levels ≥10%, with significant differences ($P \leq 0.05$) observed between 5% and 20% PPP [46]. This decrease is primarily attributed to the dilution of gluten proteins and the high fiber content of PPP. Gluten is essential for dough elasticity and gas retention, which promote lateral expansion during baking. As PPP replaces wheat flour (especially at 10–20%), gluten concentration decreases, weakening the dough structure and limiting radial spread. Furthermore, the insoluble dietary fiber in PPP (17.26%) absorbs substantial water, increasing dough viscosity and reducing its flowability. The thicker, less extensible dough resists spreading, resulting in a lower spread ratio. These data agreed with those in [47], stating that an increase in pumpkin flour substitution resulted in a linear reduction in the diameter and spread ratio of the biscuits.

Table 4. Impact of PPP on the weight and physical properties of cookies.

Samples	Weigh (g)	Diameter W (mm)	Thickness T (mm)	Spread ratio (W/T)
Control cookies	$12.87^{d} \pm 0.36$	$57.33^{a} \pm 0.88$	$4.53^{a} \pm 0.03$	$12.65^{a} \pm 0.27$
Cookies with PPP 5%	$13.61^{c} \pm 0.36$	$54.33^{ab} \pm 0.33$	$4.77^{a} \pm 0.27$	$11.44^{ab} \pm 0.67$
Cookies with PPP 10%	$14.09^{bc} \pm 0.10$	$54.00^{ab} \pm 1.00$	$4.93^{a} \pm 0.29$	$11.02^{b} \pm 0.65$
Cookies with PPP 15%	$14.27^{ab} \pm 0.14$	$52.67^{bc} \pm 1.76$	$4.97^{a} \pm 0.26$	$10.63^{b} \pm 0.24$
Cookies with PPP 20%	$14.82^{a} \pm 0.12$	$50.00^{c} \pm 1.15$	$5.03^{a} \pm 0.27$	$9.98^{b} \pm 0.40$

PPP refers to Pumpkin Peel Powder. The data presented are the mean ± standard error (SE), with a sample size of 3. Mean values in the same column that share the same superscript do not exhibit significant differences ($P \leq 0.05$).

The diameter and spread ratio of the cookies decreased progressively with increasing PPP substitution. The control cookies exhibited the highest diameter (57.33 mm) and spread ratio (12.65), whereas the values declined to 50.00 mm and 9.98, respectively, at 20% PPP. This reduction is primarily attributed to the dilution of gluten-forming proteins, as PPP contains no gluten. A weaker gluten network reduces the dough's gas retention capacity, thereby limiting radial expansion during baking. In addition, the high dietary fiber content of PPP (17.26%) absorbs substantial water, increasing dough viscosity and reducing flowability, which further restricts lateral spread. The competitive water absorption between fiber and starch also limits starch gelatinization and gluten hydration, both essential for optimal dough development. These combined effects result in smaller-diameter cookies with a lower spread ratio. Similar findings have been reported by Saewan and George and Noor Aziah et al. [48,49].

3.6. Color attributes of cookies containing different levels of PPP

Color characteristics L*, a*, and b* of the cookie surfaces were determined, and the obtained results are presented in Table 5. As can be expected, partial replacement of wheat flour with PPP at 5, 10, 15, and 20% caused a clear significant ($P < 0.05$) decrease in lightness (L^{*}) of the cookies at 63.17, 59.86, 57.25, and 54.44, respectively, as compared to 72.68 given by the control cookies. Conversely, the redness (a*) and yellowness (b*) of the cookies showed a significant ($P < 0.05$) gradual increase

with the rising level of PPP substitution, compared to the control sample. These results can likely to be attributed to the yellow color of PPP, as outlined in Table 2.

The hue of biscuits prepared with peel flour exhibits a tendency to transition toward a greenish-yellow shade as the substitution ratio escalates, as documented in [48]. The observed coloration in biscuits can be ascribed to the presence of carotene and chlorophyll pigments inherent in fruit peels. Alterations in carotenoids and other colorants, which influence the color and quality of the product, may stem from the temperature and oxidation processes encountered during the drying stage. The hue of culinary items serves as a vital indicator of quality, potentially reflecting changes in the quality of the food as a result of processing and other variables. The distinctive yellow shade, credited to the carotene pigment in pumpkin fruit, augments the color appeal of the product when pumpkin flour is integrated into the mixture [50] and [51]. Moreover, throughout the baking procedure, there may be an amplification of caramelization reactions involving starch and sugars, leading to the production of darker-colored products [52]. The researchers in [53] discovered that an increased level of pumpkin incorporation resulted in products with a darker hue.

Table 5. Effect of pumpkin peel powder on the cookies color parameters.

Samples	L*	a*	b*
Control cookies	$72.68^{a} \pm 0.39$	$0.54^{c} \pm 0.47$	$25.62^{c} \pm 0.32$
Cookies with PPP 5%	$63.17^{b} \pm 0.26$	$1.97^{bc} \pm 0.55$	$28.77^{a} \pm 0.29$
Cookies with PPP 10%	$59.86^{c} \pm 0.39$	$3.47^{ab} \pm 0.82$	$28.95^{a} \pm 0.40$
Cookies with PPP 15%	$57.25^{d} \pm 0.39$	$4.10^{a} \pm 0.03$	$27.64^{ab} \pm 0.20$
Cookies with PPP 20%	$54.44^{e} \pm 0.94$	$5.10^{a} \pm 0.36$	$27.52^{ab} \pm 0.70$

PPP refers to Pumpkin Peel Powder. The data presented are the mean ± standard error (SE), with a sample size of 6. Mean values in the same column that share the same superscript do not exhibit significant differences ($P \leq 0.05$). The terms L*, a*, and b* represent lightness, redness, and yellowness, respectively.

3.7. Determination of phenolic compounds and antioxidant activity (DPPH) of cookies

The impact of replacing wheat flour with PPP at varying percentages on total phenolic content (TPC) and DPPH radical scavenging activity of the prepared cookies is presented in Figure 4. TPC increased significantly ($P \leq 0.05$) with increasing PPP substitution, rising from 1.15 mg GAE/g (control) to 4.38, 5.61, 6.35, and 6.93 mg GAE/g for cookies containing 5%, 10%, 15%, and 20% PPP, respectively. This dose-dependent increase directly reflects the high phenolic content of raw PPP (10.91 mg GAE/g, Table 2). Pumpkin peels are rich in phenolic acids (e.g., caffeic, ferulic, p-coumaric, and sinapic acids), flavonoids (e.g., quercetin, kaempferol, and catechins), and hydrolyzable tannins (Hussain et al. (2021) [5]. During cookie baking (175°C for 15 min), heat can degrade and enhance the extractability of phenolics. Moderate thermal processing breaks down cell wall matrices, releasing bound phenolics, which likely accounts for the retention of substantial phenolic content in the final cookies. Similar trends have been reported for pumpkin peel-enriched biscuits by Ghendov-Mosanu et al. [24] and Staichok et al. [38].

The antioxidant activity followed the same progressive trend, increasing from 2.65% (control) to 4.55%, 9.85%, 13.70%, and 18.76% for 5–20% PPP, respectively (Figure 4). This enhancement is attributed to the cumulative effect of multiple antioxidant classes in PPP. Carotenoids (particularly β-carotene, lutein, and zeaxanthin) are potent singlet oxygen quenchers, while phenolic compounds

act as hydrogen donors and metal chelators. The observed DPPH scavenging activity correlates strongly with TPC (R^2 = 0.98), indicating that phenolics are the primary contributors. However, carotenoids and residual flavonoids also contribute synergistically. The slight reduction in activity relative to raw PPP (26.95%) may be due to partial thermal degradation of heat-sensitive compounds during baking, as well as possible Maillard reaction products that can either enhance or mask antioxidant activity.

Our findings are consistent with those of Ghendov-Mosanu et al. [24], who reported that shortbread cookies enriched with pumpkin powder exhibited increased TPC and DPPH scavenging activity proportional to the level of pumpkin addition. Gebremariam et al. [54] similarly observed elevated antioxidant activity in wheat-pumpkin seed composite flour cookies, confirming that seed and peel fractions of pumpkin contribute significant antioxidant potential, albeit with different phenolic profiles. The dose-dependent increase observed in our study (5–20% PPP) provides a clear quantitative relationship that can guide formulation for desired antioxidant levels. [55,56]. The results demonstrate that PPP is an effective natural antioxidant source for cookie fortification. Even at 20% substitution, the antioxidant activity (18.76%) represents a seven-fold increase over control cookies. This suggests that PPP-enriched cookies could offer improved oxidative stability during storage, in addition to potential health benefits associated with dietary phenolic intake.

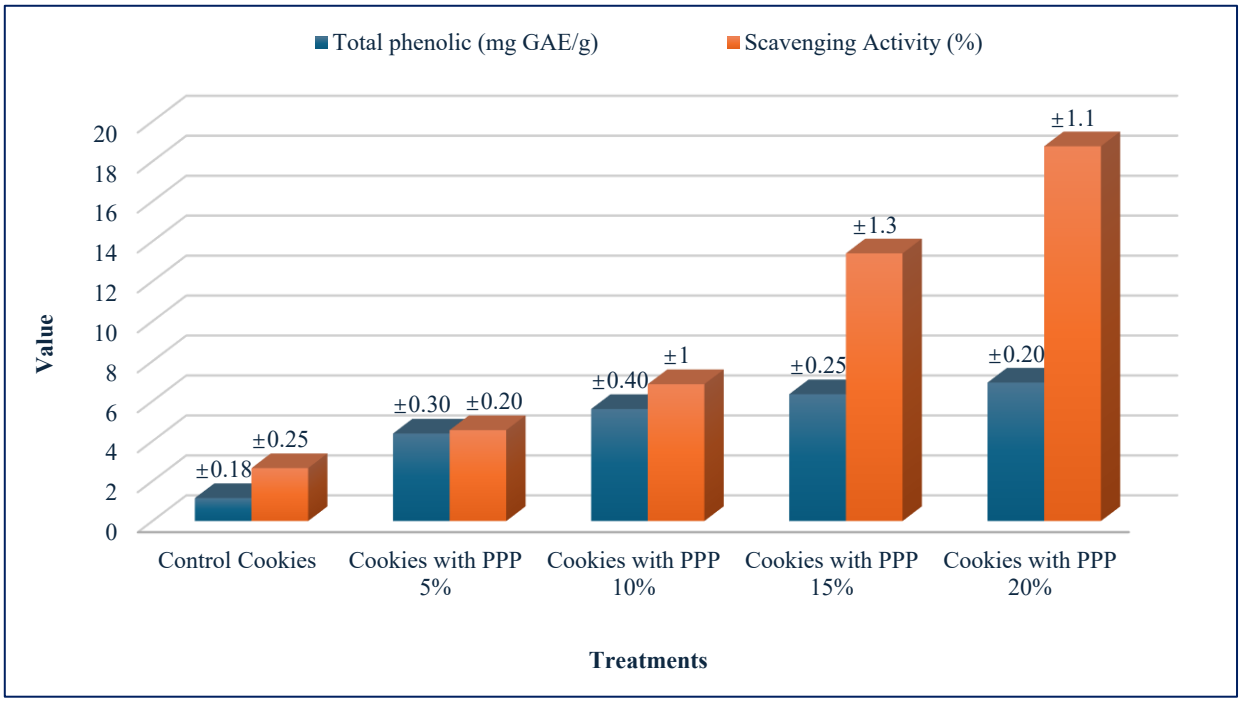


Figure 4. Total phenolic content (TPC, mg GAE/g) and DPPH radical scavenging activity (%) of cookies enriched with different levels of pumpkin peel powder (PPP). Data are presented as mean ± SE (n = 3). Different superscript letters for each parameter indicate significant differences ($P \leq 0.05$).

3.8. Hardness and fracturability of cookies

Hardness and fracturability are important indicators of cookie quality, reflecting the influence of PPP on texture throughout storage and shelf life (Figure 5). The incorporation of PPP reduced cookie hardness from 12.54 N in the control to 9.99 N at 5% PPP, with further reductions at higher substitution levels, while fracturability increased from 2.87 mm in the control to a range of 7.82–10.92 mm across the 5–20% PPP treatments. These changes indicate that PPP-enriched cookies became less brittle and more deformable. Four factors explain this trend. First, the higher fat content of PPP-enriched cookies (20.79–22.55% vs. 20.00% in the control) acts as a plasticizer, lubricating the starch–protein matrix and reducing the formation of rigid, brittle structures during baking. Second, the high dietary fiber content of PPP (17.26%) disrupts the continuous gluten network, creating a more heterogeneous and less cohesive internal structure that hinders crack propagation and increases the distance required for complete fracture. Third, the lower protein content in PPP-enriched cookies (6.87–7.40% vs. 8.80% in the control) weakens the overall matrix, making it more flexible rather than brittle. Fourth, the higher moisture content (6.23% at 20% PPP vs. 5.55% in the control) helps maintain a softer texture and thus greater deformability. Together, these effects produce cookies that resist sudden fracture and break down more gradually under compression. Similar observations have been reported by Ghendov-Mosanu et al. [24] for pumpkin powder-enriched shortbread cookies, while Gebremariam et al. [54] reported comparable force values (13.32–13.72 N) for wheat–pumpkin seed composite cookies.

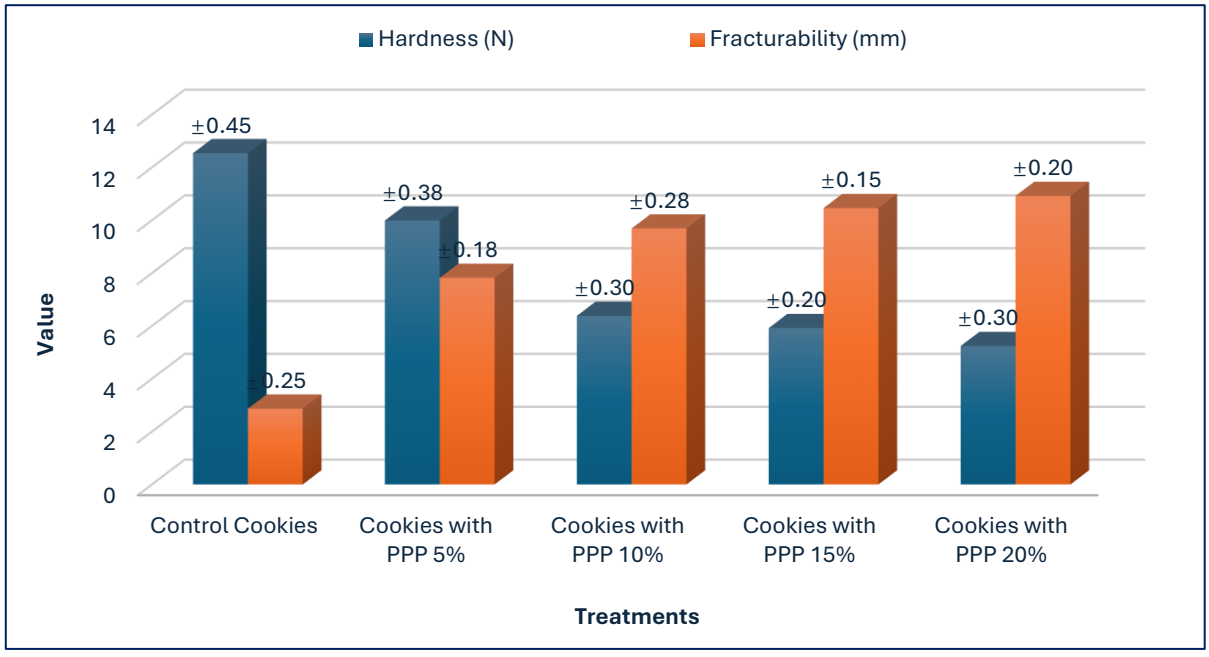


Figure 5. Texture analysis of cookie samples incorporated with different ratios of PPP.

3.9. Organoleptic properties of cookies containing different levels of PPP

Table 6 and Figure 6 illustrate the effect of various levels of PPP on the sensory characteristics of the enriched cookies. Adding PPP did not affect the appearance or surface color of cookies judged by panelists except at 20% PPP, where a slight difference was noted compared to control cookies. No

significant differences ($P < 0.05$) were found between control cookies and those containing 5% and 10% PPP for any of the sensory attributes tested.

Consistent with the instrumental hardness data (Figure 5), panelists reported a significant decrease in hand-texture scores for cookies with 15% and 20% PPP (both scored 6.5) compared to control cookies (8.1). This progressive decline in texture acceptability is primarily attributed to the high dietary fiber content of PPP (17.26%). Insoluble fiber particles physically disrupt the continuous gluten–starch matrix, creating a coarser, more granular mouthfeel that panelists perceived as less smooth and more crumbly. Additionally, the reduced gluten content in high-substitution cookies (due to dilution with gluten-free PPP) weakens the cohesive structure, resulting in a less uniform texture. These textural changes became noticeable at 15% PPP and more pronounced at 20% PPP, consistent with the fracturability data (Figure 5). Saewan and George [48] similarly noted that biscuit texture initially met panelist satisfaction but diminished significantly as the replacement ratio increased due to increased hardness.

The same trend was observed for taste and aroma. Substitution levels up to 10% PPP remained acceptable, whereas 15% and 20% PPP caused significantly ($P \leq 0.05$) lower flavor scores. The decline in flavor is explained by two factors. First, pumpkin peel contains bitter and astringent compounds, including certain phenolic acids, flavonoids, and alkaloids, which become more perceptible as PPP substitution exceeds 10%. Second, the intense characteristic aroma of pumpkin peel (described by some panelists as "earthy" or "vegetal") may be pleasant at moderate levels but becomes overpowering at higher concentrations, masking the desirable buttery and sweet notes of traditional cookies. Panelists reported that cookies with 15% and 20% PPP had a "strong pumpkin aftertaste" and "less sweet aroma," contributing to lower flavor acceptance. Notably, biscuits prepared with 6% pumpkin peel flour have been reported to emanate a tea-like aroma, attributed to catechins (a flavonoid compound found in pumpkin peels, tea, and cacao beans) [57].

Regarding overall acceptability (the sum of all attributes), no significant difference ($P \leq 0.05$) was observed between control cookies (8.4) and cookies containing 5% PPP (8.2) or 10% PPP (7.7). Cookies with 15% and 20% PPP received overall acceptability scores of 6.5 and 6.2, respectively, indicating that they were not rejected by panelists but were of lower sensory quality. The reduced overall acceptability at higher PPP levels directly reflects the cumulative negative impact of coarser texture and less balanced flavor. Nevertheless, all scores remained above 6 ("like slightly") on the 9-point hedonic scale, and the typical consumer rejection threshold was below 5 ("neither like nor dislike"). Thus, while 5–10% PPP is optimal for maintaining high acceptability (scores >7.7), 15–20% PPP still yields sensorially acceptable products. These findings are consistent with Anurag and Sharma [43], who reported acceptable cookies with 20% pumpkin flour, and with Hamed et al. [45], who observed high sensory scores for biscuits fortified with 20% pumpkin peel powder. See EF et al. [58] and Chhabra et al. [59] also concluded that adding whole pumpkin flour increased dietary fiber content and antioxidant activity, with the highest sensory scores observed at 10% substitution.

Table 6. Sensory evaluation of cookies incorporated with pumpkin peel powder.

Treatments	Appearance (9)	Color (9)	Texture (9)	Taste (9)	Aroma (9)	Overall acceptability (9)
Control cookies	$8.1^{a} \pm 0.23$	$7.9^{a} \pm 0.28$	$8.1^{a} \pm 0.18$	$8.3^{a} \pm 0.21$	$8.3^{a} \pm 0.20$	$8.4^{a} \pm 0.22$
Cookies with PPP 5%	$8.0^{a} \pm 0.26$	$8.1^{a} \pm 0.31$	$7.8^{a} \pm 0.21$	$8.1^{a} \pm 0.31$	$8.0^{a} \pm 0.30$	$8.2^{a} \pm 0.21$
Cookies with PPP 10%	$7.9^{ab} \pm 0.21$	$7.9^{a} \pm 0.18$	$7.5^{a} \pm 0.34$	$7.4^{ab} \pm 0.30$	$7.6^{a} \pm 0.28$	$7.7^{a} \pm 0.21$
Cookies with PPP 15%	$7.4^{ab} \pm 0.22$	$7.4^{ab} \pm 0.22$	$6.5^{b} \pm 0.35$	$6.6^{bc} \pm 0.37$	$6.5^{b} \pm 0.42$	$6.5^{b} \pm 0.38$
Cookies with PPP 20%	$7.1^{b} \pm 0.36$	$6.9^{b} \pm 0.39$	$6.5^{b} \pm 0.28$	$6.3^{c} \pm 0.48$	$6.4^{b} \pm 0.45$	$6.2^{b} \pm 0.34$

PPP refers to Pumpkin Peel Powder. The data presented are the mean ± standard error (SE), with a sample size of 10. Mean values in the same column that share the same superscript do not exhibit significant differences ($P \leq 0.05$).

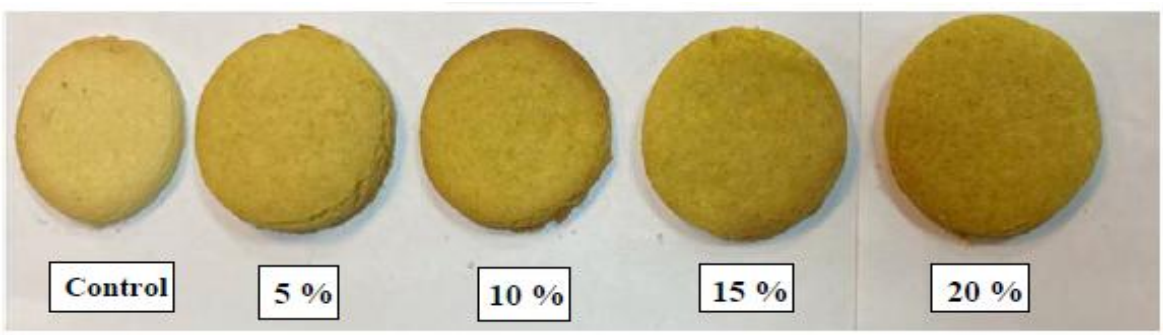


Figure 6. Color and appearance of cookies samples enriched with different levels of PPP.

4. Conclusions

In conclusion, PPP is an effective functional ingredient for improving the nutritional, bioactive, and textural properties of cookies. PPP is rich in dietary fiber (17.26%), ash (6.70%), lipids (4.90%), total phenolics (10.91 mg GAE/g), and DPPH scavenging activity (26.95%), with a distinctive yellow-red color (L = 61.66, a = 3.27, b* = 31.32). Substituting wheat flour with 5–20% PPP progressively increased cookie ash (up to 1.47%), crude fiber (up to 2.93%), total phenolics (up to 6.93 mg GAE/g), and DPPH activity (up to 18.76%), while protein content decreased modestly from 8.80% to 6.87%. Instrumental analysis revealed that PPP addition reduced cookie hardness from 12.54 N to 9.99 N at 5% PPP and increased fracturability from 2.87 mm to 10.92 mm at 20% PPP, indicating a less brittle, more deformable texture; however, the spread ratio declined progressively at 15–20% PPP due to gluten dilution and increased dough viscosity, while cookie color was not adversely affected at any substitution level. Sensory evaluation showed that cookies with 5% and 10% PPP were equally acceptable as the control (overall acceptability 8.2 and 7.7 vs. 8.4 on a 9-point hedonic scale), whereas cookies with 15% and 20% PPP received lower but still acceptable scores (6.5 and 6.2), well above the consumer rejection threshold of 5. This study provides the first reports on amylograph

gelatinization parameters of PPP-fortified doughs, instrumental texture (hardness and fracturability) of PPP-enriched cookies, and functional hydration properties (water holding capacity, oil holding capacity, bulk density, swelling index) of Saudi Arabian pumpkin peel powder. Limitations include the absence of storage stability assessment, oxidative changes over time, bioavailability studies of bioactive compounds after baking, and the use of a trained rather than a consumer-based sensory panel; results may not generalize to other pumpkin cultivars or growing regions. Practically, PPP can be incorporated up to 20% in cookies to enhance fiber, mineral, and antioxidant content with acceptable sensory properties; the optimal formulation for high overall acceptability is 5–10% PPP, whereas 15–20% PPP is suitable for nutrition-targeted products where moderate sensory compromise is acceptable. Thus, PPP represents an accessible, cost-effective natural source of minerals, fiber, and bioactive compounds that improves cookie nutritional value while potentially reducing wheat flour demand.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare no conflict of interest. Ammar AL-Farga is the Guest Editor of special issue "The development and application of antioxidant-active foods" for AIMS Agriculture and Food. Ammar AL-Farga was not involved in the editorial review and the decision to publish this article.

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