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Utilization of pear pomace as a functional additive in biscuit production: Physicochemical and sensory evaluation**

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Abstract. Employing pear pomace, a substantial by-product of juice production comprising up to 40% of the pear's mass, holds promise for enhancing sustainability in the fruit industry and augmenting the nutraceutical and health-promoting potential of functional foods, such as biscuits. This study aimed to assess the physicochemical properties and sensory evaluation of biscuits with 5-25% of wheat flour replaced by pear pomace powder. The study assessed protein, ash, fat, soluble and insoluble fiber, available carbohydrates, total phenolic compounds, and antioxidant activity against DPPH$^{\cdot}$ and ABTS$^{\cdot}$ radicals, alongside colour and texture analyses (cutting force), and sensory evaluation using a 9-point hedonic scale. Incorporating pear pomace into wheat biscuits enhanced dietary fiber and ash content, reduced protein and available carbohydrates, and correlated with higher total phenolic content and antioxidant activity as pomace levels increased. The inclusion of pear pomace led to darker, redder, and less yellow biscuits, with a corresponding decrease in cutting force as the concentration of the fruit additive increased. During sensory analysis, biscuits with 10% wheat flour replaced by pear pomace powder scored higher in overall acceptability than those without additives, while ratings for smell, taste, colour, and texture notably decreased only at the highest additive level (25%).

Keywords: food additives, by-product, pear waste, cookies, enrichment, composition

1. INTRODUCTION

Shortbread biscuits belong to the category of convenience foods, which are highly popular among consumers. Their production typically involves four basic ingredients: flour, fat, sugar, and whole eggs or egg yolks. While these ingredients result in high-calorie final products, they often have low health-promoting value. Consumers are increasingly seeking foods with high nutritional and dietary value, along with good sensory and structural qualities. New trends in biscuit production involve the use of various plant-based additives to reduce calorie content and enhance health benefits by partially replacing wheat flour with plant ingredients rich in fiber, minerals, and bioactive compounds (Krajewska and Dziki, 2023a). Increasingly, by-products of the food industry, such as fruit (Raczkowska *et al.*, 2024) and vegetable (Salem *et al.*, 2020) pomace, are being used in the production of cereal products, including biscuits. This utilization of production residues offers several benefits. Besides improving nutritional value, it helps reduce food waste and lower production costs. Furthermore, the incorporation of these by-products can positively impact the sensory acceptability of products (Nakov *et al.*, 2020), as they often contribute unique flavours, colours,

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and textures. Due to their high antioxidant activity, these by-products can enhance the shelf-life of products (Rațu *et al.*, 2023), helping to maintain freshness and prevent spoilage. Additionally, the bioactive compounds present in these by-products have been shown to have preventive and therapeutic effects on a range of diseases (Machado *et al.*, 2021), making them an attractive option for health-conscious consumers. Overall, this approach aligns with the growing consumer demand for sustainable and nutritious food options, while also supporting environmental and economic sustainability in the food industry.

An intriguing candidate for enhancing food products is pear pomace, a significant by-product of juice production, constituting approximately 40% of the pear's mass (Peng *et al.*, 2022). In 2022, global pear production was estimated at approximately 26.3 million metric tons, with Europe contributing around 2.5 million metric tons (FAOSTAT, 2022), indicating substantial potential for utilizing pear pomace in various food applications. Rich in dietary fiber, pear pomace boasts approximately 47% insoluble fiber and 10% soluble fiber, as reported by Yan *et al.* (2019). Studies have highlighted its potential to bolster gut microbiota and combat obesity in high-fat diet-fed rats, attributed to its insoluble fiber fractions (Chang *et al.*, 2017). Furthermore, the pulp, peel, seeds, and leaves of pears are rich sources of various polyphenolic compounds (Kolniak-Ostek, 2016), containing them in concentrations ranging from 5 326.7 to 234.2 mg $100g^{-1}$ of dry matter (d.m.), depending on the plant part. Due to its elevated moisture content and water activity, proper preservation methods are necessary for pear pomace to mitigate rapid degradation, often requiring effective drying techniques. In previous studies (Krajewska *et al.*, 2024), where pear pomace underwent contact and freeze-drying at varying temperatures, the freeze-drying process at a plate temperature of 20°C yielded the highest concentrations of bioactive compounds and antioxidant activity. Despite its nutritional promise, research exploring pear pomace's potential in food fortification remains underexplored compared to apple pomace counterparts. Bozdogan *et al.* (2022) found that pear pomace powder could be a valuable ingredient in gluten-free quinoa-based biscuits. Incorporating 4 and 8% of the powder did not lead to a decrease in overall liking scores during sensory evaluation compared to the control. Additionally, incorporation of pomace powder increased hardness and decreased brightness of the final product, with these attributes dependent on the amount of additive used. Given wheat's prominence as a major grain in global agricultural production there exists a research gap regarding the impact of enriching shortbread biscuits with powdered pear pomace. The utilization of pear pomace in food products not only addresses waste reduction in fruit processing but also offers a sustainable approach to enhance nutritional content and bioactive compounds in consumer goods.

Therefore, this study aims to evaluate the physicochemical properties and sensory attributes of shortbread biscuits fortified with powdered pear pomace. Our investigation encompasses analyses of basic chemical composition, antioxidant activity, colour, and texture across various formulations incorporating pear pomace powder.

2. MATERIALS AND METHODS

2.1. Reagents and raw materials

The following reagents were used for the analyses: $ABTS^{\cdot}$ (2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid)), $DPPH^{\cdot}$ (1,1-diphenyl-2-picrylhydrazyl), Folin-Ciocalteu reagent, sodium bicarbonate, and potassium persulfate (Sigma-Aldrich GmbH, Steinheim, Germany). Fully ripe pears (Conference variety), wheat flour, butter, sugar, and eggs were purchased from a local store.

2.2. Obtaining pear pomace

Pear pomace was obtained by pressing fresh pears (sliced, with seed nests and stalks removed) using a twin-screw juicer (Angel 5500, Angel Juicers, South Korea). The pomace was then placed in a freezer chamber (GTL-4905, Liebherr, Sweden) and frozen at -30°C. After 24 h, it was subjected to freeze-drying using an Alpha 1-4 Martin Christ freeze-dryer (Gefriertrocknungsanlagen GmbH, Germany) at a heating plate temperature of 20°C (± 2°C). The freeze-dried pomace was subsequently ground using a knife mill at 1 000 W, 10 000 rpm (GRINDOMIX GM-200, Retsch, Germany).

2.3. Biscuits preparation

Pear pomace biscuits (PPB) were prepared by replacing 5 (PPB5), 10 (PPB10), 15 (PPB15), 20 (PPB20), and 25% (PPB25) of the wheat flour with powdered pear pomace. The control sample (PPB0) contained no fruit powder. Initially, the dry ingredients (300 g of wheat flour, 50 g of sugar, and the appropriate amount of ground pear pomace) were mixed for 3 minutes using a mixer (KitchenAid, Heavy Duty mixer, T-5KPM5EER, USA). Then, 160 g of butter was added, and mixing continued for an additional 3 min until a crumbly consistency was achieved. Subsequently, an egg was added, and the dough was mixed for 5 min at low speed. The dough was rolled out into sheets with a thickness of 6 mm, and biscuits were cut out manually using 40 mm diameter stainless steel cutters. The biscuits were baked in a convection oven (Rational, CMP 61, Germany) at 200°C for 15 min. Before testing, the biscuits were cooled to room temperature (20-21°C).

2.4. Basic chemical analysis

The chemical composition analysis was conducted using AACC (American Association of Cereal Chemistry Approved Methods 2021) and AOAC (2021) methods. Ash content was determined according to AACC method 08-01.

Total protein content was measured using the Kjeldahl method (AACC 46-08). Free fat content was determined through continuous extraction using the SoxtecTM8000 system with application AN 310 (FOSS, Sweden) and hexane as the solvent. Total dietary fiber content, including insoluble and soluble dietary fiber, was determined using enzymatic methods (AACC 32-05, AACC 32-21, AOAC 991.43, and AOAC 985.29). The content of available carbohydrates was calculated by subtracting the sum of the other components from 100. The measurements were performed in three repetitions.

2.5. Total phenolic content and antioxidant activity assesment

One gram of ground PPB and plain biscuits was extracted three times with 5 ml of a methanol:distilled water (1:1, v/v) mixture for half an hour, using a Multi Bio RS-24 rotator (Biosan Sia, Latvia). The samples were then centrifuged for 5 minutes at 5000 rpm (LC8 3500 Benchmark, USA). The supernatants were collected, combined and were utilized for subsequent analysis.

The total phenolic content (TPC) was measured using the Folin-Ciocalteau reagent method (Singleton and Rossi, 1965). TPC was assessed in triplicate and reported as mg gallic acid equivalent (GAE) g^{-1} d.m. Moreover, two antioxidant assays were conducted: DPPH$^{\cdot}$ (Brand-Williams *et al.*, 1995) and ABTS$^{\cdot}$ radical scavenging assay (Re *et al.*, 1999). The results were expressed as the concentration inducing a response halfway between the baseline and the maximum (EC_{50} index) (Singh *et al.*, 2020). The TPC and antioxidant activity (AA) measurements were performed in three repetitions using the Spectrophotometer Model 9423 from Alt (East Lyme, CT, USA).

2.6. Colour assesment

The colour coordinates of both the control and enriched biscuits were measured five times for each sample using a colourimeter (NR20XE, Shenzhen Threenh Technology Co., China) in the CIE L^* a^* b^* colour space. The L^*, a^*, and b^* parameters were determined. L^* values represent the degree of brightness, ranging from black (0) to white (100). Positive a* values denote the intensity of redness, while positive b^* values denote the intensity of yellowness. Additionally, the total colour difference (*TCD*) between the control and PPB was calculated using the following formula:

$$TCD = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2}.$$

2.7. Cutting test

The texture of PPB and the control sample was measured using a Zwick testing machine (Z020/TN2S, Ulm, Germany). Cutting force was used as an indicator of cookie hardness. The samples were centered beneath the blade for cutting. A single cookie was cut with a 1 mm thick blade at a speed of 20 mm min^{-1} until the distance between the knife and the plate reduced to 0.1 mm. The cutting force was recorded and expressed in newtons (N). The test was conducted 2 hours after baking, once the cookies had cooled. The test was repeated five times for each sample.

2.8. Sensory assesment

Consumer acceptance of the biscuits was evaluated using a 9-point hedonic scale, ranging from 1 (dislike very much) to 9 (like very much). All biscuit samples were assessed by 62 panelists for appearance, colour, aroma, taste, texture, and overall acceptability. The analysis was conducted under daylight conditions at 20°C. Consumers were informed about the study's purpose prior to testing and provided their consent in accordance with university ethics committee requirements. Approval for the study was previously obtained from the Ethics Committee for Scientific Research Involving Humans at the University of Life Sciences in Lublin.

2.9. Statistical analyses

To assess the significance of differences between the means of other measurements, ANOVA followed by Tukey's test ($p<0.05$) was employed. Non-parametric Kruskal-Wallis tests were utilized to detect significant differences ($p<0.05$) among the sensory evaluations. Statistical analyses were performed using Statistica 14.0 software (StatSoft, Inc., Tulsa, OK, USA).

3. RESULTS AND DISSCUTION

3.1. Chemical composition of wheat flour, pear pomace and biscuits

Numerous authors utilize fruit processing waste to enrich cereal products, thereby enhancing their nutritional value (Šeregelj *et al.*, 2022; Zarzycki *et al.*, 2024). Table 1 presents the basic composition (including protein, fat, ash, soluble fiber, insoluble fiber, total fiber, and total available carbohydrates) of PPB enriched with different percentages of additive, along with pear pomace powder and the wheat flour used for baking. The results indicate that pear pomace is a valuable source of fiber, containing 57.87%, which is 21.8 times more than wheat flour. For comparison, date fruit pomace contains 45.5% fiber (Haris *et al.*, 2023), apple pomace 49.62% fiber (Kruczek *et al.*, 2023), and micronized grape pomace 60.77% fiber (Bender *et al.*, 2020). Additionally, pear pomace is richer in minerals compared to wheat flour, as indicated by its 3.8-fold higher ash content. Consequently, PPBs contained significantly more fiber (both soluble and insoluble) and ash compared to biscuits without pear pomace. Replacing 25% of the flour with fruit powder resulted in a 6.9-fold increase in total fiber content in biscuits compared to the control product, with and soluble dietary fiber (SDF) increasing from 1.22 to 3.52% and insoluble dietary fiber (IDF) increasing

Table 1. Basic composition of wheat flour, pear pomace and pear pomace biscuits (% dry mass)

Sample	Protein	Fat	Ash	Soluble fiber	Insuoluble fiber	Total fiber	Total avaliable carbohydrates
WF	10.82 ± 0.06^{B}	1.13 ± 0.04^{B}	0.531 ± 0.004^{A}	1.41 ± 0.04^{A}	1.25 ± 0.02^{A}	2.66 ± 0.03^{A}	84.86 ± 0.12^{B}
PP	2.64 ± 0.02^{A}	0.92 ± 0.01^{A}	1.993 ± 0.025^{B}	10.63 ± 0.37^{B}	47.24 ± 0.08^{B}	57.87 ± 0.43^{B}	36.58 ± 0.43^{A}
PPB0	6.25 ± 0.03^{f}	29.36 ± 0.08^{a}	0.207 ± 0.015^{a}	1.22 ± 0.04^{a}	1.05 ± 0.03^{a}	2.27 ± 0.01^{a}	61.92 ± 0.09^{c}
PPB5	6.09 ± 0.02^{e}	29.35 ± 0.03^{a}	0.309 ± 0.002^{b}	1.82 ± 0.03^{b}	3.82 ± 0.58^{b}	5.65 ± 0.60^{b}	58.60 ± 0.59^{c}
PPB10	5.80 ± 0.03^{d}	27.34 ± 3.44^{a}	0.383 ± 0.002^{c}	2.25 ± 0.03^{c}	5.62 ± 0.04^{c}	7.87 ± 0.04^{c}	58.61 ± 3.42^{c}
PPB15	5.65 ± 0.04^{c}	29.31 ± 0.12^{a}	0.483 ± 0.002^{d}	2.75 ± 0.02^{d}	7.66 ± 0.11^{d}	10.41 ± 0.11^{d}	54.14 ± 0.22^{b}
PPB20	5.49 ± 0.02^{b}	29.27 ± 0.14^{a}	0.540 ± 0.047^{d}	3.11 ± 0.03^{e}	9.84 ± 0.02^{e}	12.95 ± 0.04^{e}	51.74 ± 0.13^{ab}
PPB25	5.34 ± 0.02^{a}	29.34 ± 0.07^{a}	0.651 ± 0.013^{e}	3.52 ± 0.04^{f}	12.15 ± 0.09^{f}	15.67 ± 0.13^{f}	49.00 ± 0.15^{a}

PPB0 – 0%, PPB5 – 5%, PPB10 – 10%, PPB15 – 15%, PPB20 – 20%, and PPB25 – 25% pear pomace contents. $^{A\text{-}B}$ – mean values indicated by distinct letters exhibit statistically significant differences among raw materials samples ($p < 0.05$). $^{a\text{-}f}$ – mean values indicated by distinct letters exhibit statistically significant differences among biscuits samples ($p < 0.05$). WF – wheat flour, PP – pear pomace, PPB – pear pomace biscuits.

from 1.05 to 12.15%. SDF, which is easily fermented in the colon, is thought to have a beneficial effect on serum lipids, while IDF is associated with laxative benefits (Quiles *et al.*, 2016). Conversely, the protein content and total available carbohydrates in biscuits decreased as the amount of pear pomace increased. There was a 1.2-fold decrease in protein and a 1.3-fold decrease in total available carbohydrates in product with the highest pomace content. The addition of fruit powder did not affect the fat content of the biscuits, despite pear pomace having less fat compared to wheat flour. Moreover, a strong correlation was observed between the amount of pear pomace powder in the biscuits and the ash, SDF, IDF, and total fiber content ($r = 0.991$, 0.997, 0.996, 0.998 at $p = 0.001$, respectively). There was also a negative correlation between the additive content and the protein and total available carbohydrates ($r = -0.991$ and -0.952 at $p = 0.001$, respectively).

Table 2. Antioxidant activity and total phenolic content of pear pomace biscuits

Sample	DPPH	ABTS	TPC
PPB0	379.46 ± 7.22^{e}	300.67 ± 4.63^{f}	0.32 ± 0.01^{a}
PPB5	348.79 ± 6.11^{d}	281.08 ± 3.89^{e}	0.52 ± 0.02^{b}
PPB10	144.60 ± 3.63^{c}	193.26 ± 3.24^{d}	0.90 ± 0.02^{c}
PPB15	104.58 ± 8.71^{b}	163.19 ± 2.28^{c}	1.12 ± 0.01^{d}
PPB20	72.99 ± 0.70^{a}	133.62 ± 1.77^{b}	1.55 ± 0.02^{e}
PPB25	63.86 ± 0.35^{a}	104.90 ± 0.56^{a}	1.65 ± 0.03^{f}

DPPH – indicates the ability to neutralize DPPH radicals, expressed as EC_{50} in mg d.m. ml^{-1}, ABTS – indicates the ability to scavenge ABTS radicals, expressed as EC_{50} in mg d.m. ml^{-1}, TPC – total phenolic compounds expressed as GAE g^{-1} d.m. Other explanations on Table 1.

3.2. Antioxidant properties and total phenolic content

The AA (measured using the DPPH$^{\cdot}$ and ABTS$^{\cdot}$ methods) and TPC of biscuits are presented in Table 2. Both the DPPH$^{\cdot}$ and ABTS$^{\cdot}$ methods operate based on similar fundamental mechanisms, specifically hydrogen atom transfer and electron transfer (Christodouleas *et al.,* 2015). The DPPH$^{\cdot}$ radical can be reduced to either DPPH$_2$ or DPPH–, depending on its interaction with the antioxidant, and both the solvent and the antioxidants influence the dominant mechanism of the reaction. In contrast, ABTS$^{\cdot}$+ reaction may also yield addition and degradation products, introducing greater complexity. Additionally, the ABTS$^{\cdot}$ assay may exhibit broader reactivity towards antioxidants, including those that do not react with DPPH$^{\cdot}$ (such as certain dihydrochalcones and flavanones) (Platzer *et al.,* 2021). The inclusion of pear pomace resulted in an increase in both AA and TPC of PPB. A strong positive correlation was observed between the content of fruit powder and TPC ($r = 0.991$, $p = 0.001$), alongside a strong inverse correlation between fruit powder content and EC_{50} values against DPPH$^{\cdot}$ and ABTS$^{\cdot}$ radicals ($r = -0.924$, $p = 0.001$ and $r = -0.977$, $p = 0.001$, respectively). Pear pomace powder contains between 2.58 and 5.12 mg GAE g^{-1} d.m. with variations dependent on drying temperature, method, particle size, and extraction technique (Ferreira *et al.*, 2023; Krajewska *et al.*, 2024). The primary polyphenolic compounds in pear pomace are phenolic acids, notably quinic acid and chlorogenic acid (Krajewska *et al.*, 2024). The flavonoids present in the raw material are predominantly isocquercetin and rutin. The highest concentration of pear pomace (25%) led to a more than 5.9-fold increase in TPC of the biscuits, reaching up to 1.65 mg (GAE) g^{-1} d.m. In a study by Zlatanović *et al.* (2019), a 1.1-fold increase in TPC was noted in wheat biscuits with a 25% substitution of flour with apple pomace powder. Chumroenvidhayakul *et al.* (2023) reported a 2.9-fold increase in TPC in wheat biscuits after incorporating 5% dragon fruit peel. Furthermore, replacing 25% of flour with pear pomace resulted in a 5.2-fold increase in antioxidant activity in the $\mathrm{DPPH}^{\cdot}$ assay and a 2.3-fold increase against $\mathrm{ABTS}^{\cdot}$, compared to biscuits without the additive, as demonstrated by a decrease in EC_{50} values. The antioxidant activity against $\mathrm{DPPH}^{\cdot}$ increased with higher amounts of pear pomace, with no significant difference observed between the 20 and 25% levels. Additionally, significant correlations were found between $\mathrm{DPPH}^{\cdot}$ and $\mathrm{ABTS}^{\cdot}$ (r = 0.981, p = 0.001), $\mathrm{DPPH}^{\cdot}$ and TPC (r = -0.940, p = 0.001), and $\mathrm{ABTS}^{\cdot}$ and TPC (r = -0.981, p = 0.001). Similar correlations between TPC and AA have been documented in the literature for wheat biscuits enriched with chestnut husk extract (Pinto *et al.*, 2023) and *Lonicera japonica* extract (Cao *et al.*, 2022).

3.3. Biscuits colour

The acceptance of shortbread biscuits, hinges significantly on their colouration, which is shaped by variables such as baking techniques and ingredient selection (Krajewska and Dziki, 2023a). The addition of pear pomace significantly altered the colour of wheat biscuits (Fig. 1). Generally, the incorporation of pomace resulted in darker, redder, and less yellow biscuits, as indicated by the changes in the L^*, a^*, and b^* parameters (Table 3). The lightness of the biscuits decreased with increasing levels of additive from 5 to 15%, but remained similar at the range of 15-25%. Although the numerical values suggest that the biscuits with 20% pomace addition appear darker than those with 25% pomace addition, the statistical analysis indicated no significant differences in the L^* parameter values among the samples PPB15, PPB20, and PPB25, suggesting that the observed variations may fall within the margin of error. A marked increase in redness was observed at 5% pear pomace level, which intensified further at 10%; however, beyond this concentration, no further changes in a^* parameter were noted. The observed increase in a^* coordinate value may be attributed to the caramelization of sugars and the consequent darkening of the marc during the high-temperature heat treatment of the biscuits. This was supported by a strong inverse correlation between L^* and a^* (r = -0.982, p = 0.001). Conversely, the yellowness of the biscuits decreased significantly compared to the control when pear pomace was added at levels above 15%. Kruczek *et al.* (2023) reported a similar trend of decreased brightness and yellowness, along with increased red tones, upon the incorporation of apple pomace powder into gluten-free biscuits. *TCD* for biscuits with 5% pear pomace incorporation was less than 5 units, indicating minor differences that are likely imperceptible to consumers (Tazrart *et al.*, 2016). However, for pear pomace additions of 10% or more, the *TCD* was substantially higher, suggesting changes that are potentially noticeable by consumers.

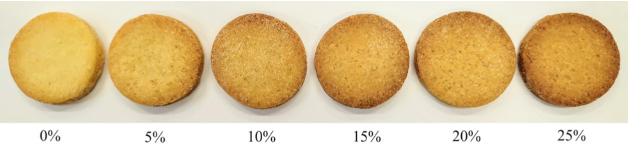

Fig. 1. Biscuits with various pear pomace powder percentages.

Table 3. Colour parameters of biscuits

Sample	L^*	a^*	b^*	*TCD*
PPB0	72.20 ± 0.62^{d}	5.38 ± 0.63^{a}	23.75 ± 1.37^{b}	-
PPB5	66.68 ± 0.33^{c}	7.18 ± 0.12^{b}	22.95 ± 0.62^{b}	4.52 ± 0.59^{a}
PPB10	61.49 ± 0.18^{b}	9.16 ± 0.44^{c}	22.27 ± 0.17^{ab}	8.41 ± 0.28^{b}
PPB15	59.40 ± 0.25^{a}	9.83 ± 0.31^{c}	20.50 ± 0.78^{a}	11.59 ± 0.80^{c}
PPB20	58.86 ± 0.14^{a}	10.26 ± 0.14^{c}	20.62 ± 0.09^{a}	12.13 ± 0.49^{c}
PPB25	59.67 ± 0.35^{a}	9.41 ± 0.37^{c}	21.29 ± 0.39^{a}	11.29 ± 0.18^{c}

L^* – lightness, a^* – redness, b^* – yellowness, *TCD* – total colour difference. $^{a\text{-}d}$ – mean values indicated by distinct letters exhibit statistically significant differences ($p < 0.05$). Other explanations on Table 1.

3.4. Texture analysis

The texture properties, particularly the hardness of biscuits (expressed as a cutting force value), are critical determinants of their quality. Consumers generally prefer biscuits with lower hardness values, though specific benchmarks for wheat biscuits have not been established. In this study, the cutting force for control biscuits was 39.88 N, while that for fortified biscuits ranged from 19.36 to 38.06 N. The hardness of biscuits fortified with pear pomace powder decreased as the content of the additive increased (Fig. 2). There was a strong correlation between the amount of the pear pomace and the cutting force (p = 0.950, r = 0.001). A significant reduction in hardness was observed with incremental increases of 10% in pear pomace substitution, where the cutting force was significantly lower at 10% substitution (32.02 N) and further reduced at 20% substitution (23.54 N). The literature reports both increases and decreases in the hardness of wheat-based products with the incorporation of fruit additives, depending on their properties. For instance, the addition of rowanberry, rosehip, or blackcurrant pomace increased the hardness of wheat biscuits, while raspberry, red currant, or chiku pomace led to a decrease (Asadi *et al.*, 2021; Tańska *et al.*, 2016; Tarasevičienė *et al.*, 2021). The reduction in cutting force observed in PPB is likely related to its high dietary fiber content, which has a strong water-binding capacity. A robust correlation was found between cutting strength and total fiber content (p = 0.988, r = 0.001). Increased dietary fiber content may disrupt the gluten network structure, potentially due to the friction of fiber particles against protein chains (Han *et al.*, 2019), resulting in a softer texture. Moreover, fiber can act as a natural emulsifier

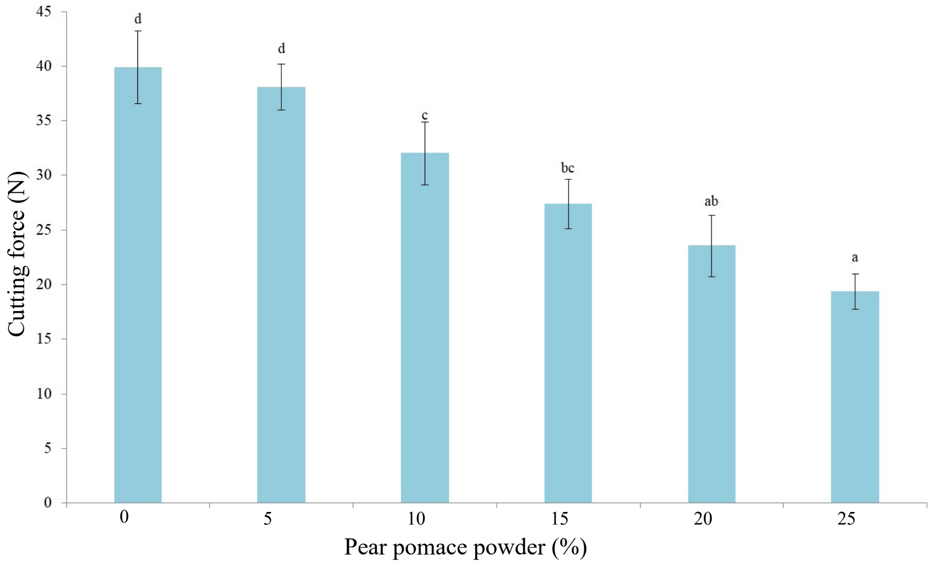

Fig. 2. Hardness of biscuits with the addition of pear pomace powder. $^{a-d}$ – mean values indicated by distinct letters exhibit statistically significant differences between means ($p < 0.05$).

(Kalla-Bertholdt *et al.*, 2021), promoting a more uniform distribution of fat and other ingredients within the dough, thus leading to a more homogeneous texture and reduced hardness in the biscuits. Additionally, the insoluble fiber fraction may increase starch viscosity, delaying its short-term retrogradation, which typically results in a harder and more brittle final product (Xu *et al.*, 2021).

3.5. Sensory evaluation of biscuits fortified with pear pomace

According to the results obtained from sensory analysis (Fig. 3), the appearance of the biscuits significantly deteriorated with the addition of 20 and 25% pear pomace powder compared to the control. In contrast, ratings for smell, taste, colour, and texture were notably lower only when the maximum amount of additive (25%) was used. Overall acceptability, which is the most critical measure in sensory analysis on the hedonic scale, was highest in biscuits where 10% of wheat flour was replaced with pomace, even outperforming the control. These biscuits received ratings ranging from 6 (moderately like) to 9 (extremely like) (Table 1S, supplementary). The lowest acceptability was observed in biscuits with a 25% pomace addition, with ratings ranging from 3 (quite dislike) to 8 (very much like). The overall ratings for the other biscuits, including the control and those with 5, 15, and 20% fruit pomace powder, did not differ significantly, ranging from 5 (neither like nor dislike) to 9 (extremely like). Rocha Parra *et al.* (2019) similarly found that replacing 15% of wheat flour with powdered apple pomace did not result in a significant change in sensory evaluations of appearance, odor, and overall acceptability, regardless of the particle size of the fruit powder, although the flavour of the biscuits improved with the addition. In a study by Ahmad *et al.* (2016), incorporating carrot pomace

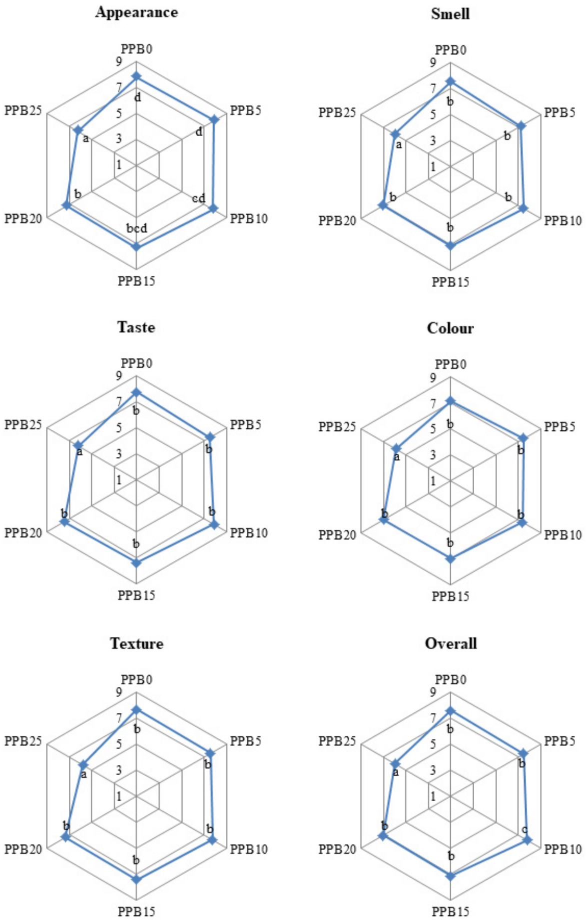

Fig. 3. Sensory evaluation of pear pomace biscuits. PPB0 – 0% pear pomace content, PPB5 – 5% pear pomace content, PPB10 – 10% pear pomace content, PPB15 – 15% pear pomace content, PPB20 – 20% pear pomace content, PPB25 – 25% pear pomace content. a-d – values indicated by distinct letters exhibit statistically significant differences ($p < 0.05$).

at levels of 10-20% led to an increase in overall acceptability, flavour, colour, and appearance, with higher content correlating with better ratings. However, texture ratings decreased when more than 15% of the additive was used, a trend also influenced by particle size. Conversely, Bora *et al.* (2019) reported a decrease in texture and flavour ratings of biscuits as the goji berry by-product content increased from 10 to 40%, while appearance ratings remained unchanged when 10% powder was added compared to biscuits without the additive. The addition of fruit pomace can either enhance or diminish sensory quality attributes, depending on the specific characteristics of the additive. The optimal content of a functional additive should be determined by balancing consumer acceptance with the nutraceutical and health-promoting properties of the product.

4. CONCLUSIONS

1. Dried and powdered pear pomace represents a significant source of dietary fiber, comprising 57.87%, with a soluble fraction of 10.63% and an insoluble fraction of 47.24%.
2. Incorporating pear pomace powder into wheat biscuits resulted in elevated levels of dietary fiber and minerals, accompanied by reduced protein and available carbohydrates.
3. Increasing the proportion of pear pomace in biscuits correlated positively with enhanced total phenolic content and antioxidant activity against DPPH$^{\cdot}$ and ABTS$^{\cdot}$ radicals.
4. The addition of pear pomace caused biscuits to exhibit darker, redder hues and reduced yellowness, with a corresponding decrease in hardness as the concentration of fruit additive increased.
5. Sensory evaluations indicated that pear pomace-enriched shortbread biscuits were well-received. Biscuits substituting 10% of wheat flour with pomace powder received higher overall acceptability ratings compared to those without additives. Ratings for smell, taste, colour, and texture declined only when the highest additive level (25%) was employed.
6. Based on the sensory evaluations, we recommend incorporating 15% pear pomace powder into biscuits, as this level preserves overall acceptability and sensory qualities comparable to biscuits without the additive while enhancing antioxidant activity and total polyphenolic content.

Conflicts of Interest: The Authors do not declare any conflict of interest.

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