Check for updates

Received: 9 November 2024 | Revised: 20 February 2025 | Accepted: 21 February 2025

DOI: 10.1111/1750-3841.70123

Journal of Food Science WILEY

ORIGINAL ARTICLE

Integrated Food Science

Enhancing the nutritional and textural properties of gluten-free shortbread biscuits: The potential of white-fleshed sweet potato flour blended with corn starch

Muhammed Ozgolet[1] | **Louiza Belkacemi**[2] | **Muhammet Arici**[1]

[1]Agricultural, Agri-food Production Techniques and Sustainable Development, Higher School of Agronomy of Mostaganem, Mostaganem, Algeria

[2]Department of Food Engineering, Faculty of Chemical and Metallurgical Engineering, Yıldız Technical University, Istanbul, Turkey

Correspondence
Muhammed Ozgolet, Department of Food Engineering, Faculty of Chemical and Metallurgical Engineering, Yıldız Technical University, Istanbul, Turkey.
Email: mozgolet@yildiz.edu.tr

Funding information
Türkiye Bilimsel ve Teknolojik Araştırma Kurumu (TUBITAK)

Abstract

Sweet potato flour (SPF) is a promising gluten-free alternative to wheat flour, though it affects the texture of shortbread biscuits. This study aimed to evaluate the potential of white-fleshed SPF, both peeled (PSP) and unpeeled (USP), as an alternative to soft wheat flour in the production of gluten-free shortbread biscuits. Specifically, this study aimed to assess how blending SPF with corn starch influences the nutritional, physical, and textural properties of shortbread biscuits. For this purpose, shortbread biscuits (B) were prepared using PSP or USP white-fleshed SPF alone (B100) or in a 1:1 mixture with corn starch (B50). Control shortbread biscuits were made from 100% wheat flour (WB) or 100% corn starch (SB). All the samples were analyzed for their proximate composition, mineral, polyphenol, and flavonoid contents. The physical and textural properties were assessed, in addition to their in vitro glycemic index (GI). Results showed that unpeeled SP biscuits (USPB100) had the highest fiber (6.63%), minerals (1.99%), polyphenols (88.85 mg gallic acid equivalent/100 g), and flavonoids (213.96 mg quercetin equivalent/100 g). PSP and USP increased hardness but improved mineral content (Na, Ca, Mg, Fe, and Zn) compared to controls. Furthermore, all the shortbread biscuits made with both PSP and USP flours, totally or mixed with corn starch, recorded an estimated GI lower than the wheat and corn starch–based shortbread biscuits. In summary, blending SPF with corn starch permitted the development of gluten-free shortbread biscuits with enhanced textural and physical properties while achieving satisfactory nutritional quality.

KEYWORDS

Algerian cultivar, corn starch, glycemic index, sweet potato, unpeeling

1 | INTRODUCTION

Shortbread biscuits are a popular ready-to-eat baked food made from dough prepared by mixing sugar, eggs, fat, and mainly energy-rich flour (Ubbor et al., 2021), making it an energy-dense snack. In fact, shortbread biscuits are a valuable energy source frequently purchased by consumers of all kinds because of their relatively affordable price and

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.
© 2025 The Author(s). *Journal of Food Science* published by Wiley Periodicals LLC on behalf of Institute of Food Technologists.

convenience. Biscuit high consumption is often related to the risk of developing diabetes, obesity, and cardiovascular diseases (Krajewska & Dziki, 2023). Indeed, shortbread biscuits are generally based on soft white wheat flour with a reduced content of nutrients, such as fibers, lysine, and major and trace elements (Li et al., 2022). Besides their low nutritional value, wheat-based shortbread biscuits contain gluten, which is excluded in a gluten-free diet. Substituting wheat with another gluten-free flour with a better nutrient profile is an alternative to cope with nutritional insufficiencies and even a solution for gluten-intolerant persons.

The use of sweet potato (SP) (*Ipomoea batatas* L. Lam.) to produce flour has gained significant interest. Indeed, SP is one of the most common starchy foods, along with remarkable amounts of dietary fiber, minerals, vitamins, and phenolic compounds (Van Chuyen & Eun, 2013). Moreover, it represents an adequate alternative to wheat in the production of wheat-based bakery products (Olatunde et al., 2019). Several studies have focused on the partial or total replacement of wheat flour by SP in bakery products, such as bread (Lu & Gao, 2011; Mitiku et al., 2018), cake (Chuango et al., 2019), and cookies/shortbread biscuits (Giri & Sakhale, 2019; Jemziya & Mahendran, 2015; Kolawole et al., 2021; Mais & Brennan, 2008). However, substituting wheat flour with SP alters shortbread biscuit's textural and sensory properties. According to Padmaja et al. (2012), the substitution of wheat flour with SP was acceptable for shortbread biscuits up to 30%. Indeed, several studies reported that using SP flour (SPF) at 100% resulted in harder cookies compared to the soft wheat-based ones (Julianti et al., 2019; Okpala & Ofoedu, 2018; Singh et al., 2008). Most studies focused on replacing wheat flour with SP-processed flour from peeled SP (PSP) tubers. However, the peel of the SP is known to be rich in minerals, dietary fibers, and bioactive compounds (Elkatry et al., 2023). Thus, the peeling process decreases the health benefits of the final product (Ray & Tomlins, 2010). Moreover, most of the studies related to shortbread biscuits produced with SP used flour made from orange-fleshed SP (OFSP) tubers (Chikpah et al., 2020; Kolawole et al., 2020; Olatunde et al., 2019). However, the nutritional and chemical constituents differ between different SP cultivars (Ayeleso et al., 2024). Therefore, this study aimed to assess the effect of incorporating flour from the purple-skinned, white-fleshed cultivar on shortbread biscuit quality. Parallelly, Julianti et al. (2019) reported that incorporating SP peel into SPF-based shortbread biscuits at different rates increased their hardness. Therefore, preparing shortbread biscuits with SP peel necessitates an additive ingredient such as starch to meet the requirements of textural and sensorial biscuit quality. Indeed, it was reported that starch is one of the important raw ingredients used in the formulation of gluten-free food (Olawoye et al., 2020) and that corn starch softens the texture of shortbread biscuits (Conforti et al., 2012). Therefore, corn starch was used alongside SPF in this study to enhance texture. The aim of the present study is to develop gluten-free shortbread biscuits using flours derived from peeled and unpeeled purple-skinned, white-fleshed SPs, either individually or blended with corn starch. The primary objective is to assess the feasibility of incorporating unpeeled purple-skinned, white-fleshed SPF to enhance the nutritional profile of the shortbread biscuits while preserving the desired textural and physical qualities of the final product.

2 | MATERIALS AND METHODS

2.1 | Materials

A purple-skinned, white-fleshed SP Blesbok cultivar was purchased from a local market. The enzymes (pepsin P7000, pancreatin P7545, invertase I4504) were purchased from Sigma Chem. Co. Amylase, amyloglucosidase, and glucose oxidase–peroxidase (GOPOD) reagent were supplied by Megazyme International Ireland Ltd. Other reagents and solvents used in this study were procured from Sigma Chem. Co. The ingredients of shortbread biscuits (wheat flour, sugar, corn starch, eggs, margarine, starch, and baking powder) were purchased from a local supermarket.

2.2 | Methods

2.2.1 | Sweet potato flour processing

A purple-skinned, white-fleshed SP Blesbok cultivar was processed into flour as described by Belkacemi (2022). Briefly, cleaned SP tubers were divided into two lots: a manually peeled batch and an unpeeled one. Both batches were finely sliced and soaked in tap water for 15 min to prevent discoloration. Afterward, each batch was blanched in water at 100°C for 5 min and then immediately immersed in cold water. After draining, both lots were dried at 60°C for 24 h. Dried SP slices were then milled and sieved through a 250 μm sieve to obtain uniform-sized flour. The flours were stored in polyethylene bags in a dry cabinet at 25 ± 2°C until use. The proximate composition of SPF was analyzed in our previous study (Belkacemi, 2022).

2.2.2 | Shortbread biscuit preparation

In order to make gluten-free shortbreads, the shortbread biscuits were prepared by substituting the wheat flour

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 The formulation of shortbread biscuits.

Ingredients	WB	SB	PSPB100	USPB100	PSPB50	USPB50
Wheat flour (g)	200	0	0	200	0	0
Corn starch(g)	0	200	0	0	100	100
Peeled sweet potato flour (PSPF) (g)	0	0	200	0	100	0
Unpeeled sweet potato flour (USPF) (g)	0	0	0	200	0	100
Margarine	100					
Iced sugar	100					
Egg yolk	32					
Starch	30					
Baking powder	5					

Note: WB: wheat-based biscuits; SB: corn starch–based biscuits; PSPB100: biscuits made from peeled sweet potato flour; PSPB50: biscuits made from peeled sweet potato flour blended with corn starch (50%–50%); USPB100: biscuits made from unpeeled sweet potato flour; USPB50: biscuits made from unpeeled sweet potato flour blended with corn starch (50%–50%).

with SPF either at 100% or blended at 50% with corn starch. Two types of control shortbreads were prepared: those made entirely from wheat flour, representing the traditional shortbread biscuits, and the others made from 100% corn starch, serving as a gluten-free biscuit control. The shortbread biscuit recipe was formulated according to prior assays in the laboratory by replacing whole eggs with egg yolks and sugar by icing one. Biscuit ingredients are reported in Table 1. Salt and vanilla were not added as ingredients to assess the typical aroma and taste of each biscuit. Shortbread biscuit dough was prepared manually as follows: Margarine was creamed with iced sugar until light and fluffy consistency was achieved, then followed by adding egg yolk and finally dry ingredients (starch, baking powder, and flour). The dough was gathered without kneading and then rolled manually and cut with a cookie cutter. All shortbread biscuits were baked in a preheated oven (Brandt BGE6140WA) for 15 min at 180°C. The shortbread biscuits were cooled at room temperature before being packed in an airtight plastic container before analysis.

2.2.3 | Proximate composition

The proximate composition was determined following the Association of Official Agricultural Chemists (AOAC) methods (AOAC 2010). Moisture content was measured by drying the samples in an oven at 105°C until a constant weight was achieved, and ash content was determined using the muffle furnace (DAIHAN FHX-14, Daihan Scientific) at 550°C for 6 h until the sample became grayish-white residues. Fat content was evaluated with the Soxhlet extraction method (5 h) using petroleum ether, and crude fiber was determined from the defatted sample. Crude protein was assessed using the Kjeldahl method with a nitrogen-to-protein conversion factor of 6.25. Carbohydrate content for energy calculation was obtained by subtracting the total ash, fat, fiber, protein, and moisture content from 100% (Naqvi et al., 2024). The total energy value (kcal) was calculated by multiplying carbohydrate and protein contents by 4 and fat content by 9 (Maia et al., 2020).

2.2.4 | Polyphenol and flavonoid content

Polyphenols and flavonoids were extracted from shortbread biscuit samples according to the method described by de Camargo et al. (2014) with slight modifications. Ground shortbread biscuits were defatted three times using hexane (1:5, w/v) and then immediately (10 g) placed in a beaker containing 100 mL of methanol–HCl (1% HCl) for phenolic compound extraction. The mixture was macerated for 24 h in the dark under continuous shaking. After that, each mixture was centrifuged at 3000 *g* (SIGMA, D-37520, 2-16KL), and then the supernatant was recovered and used for polyphenol and flavonoid assessment. Total phenolic content (TPC) was determined according to the method described by Singleton et al. (1999), and results were expressed as mg gallic acid equivalent (GAE)/100 g shortbread biscuits. The flavonoid content determination was carried out according to the method described by Zhishen et al. (1999). The results were expressed as mg quercetin equivalent (QE)/100 g shortbread biscuits.

2.2.5 | Mineral analysis

Mineral analysis of the samples was carried out according to the procedure of Yildirim and Arici (2019). Shortbread

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

biscuits were freeze-dried (Martin Christ, Beta 1-8 LSC-plus) and ground before the analysis. The mineral contents (Na, K, P, Mg, Ca, Fe, and Zn) were quantified by using inductively coupled plasma atomic emission spectroscopy using ICPE-9000 spectrometer. For analysis, 0.5 g of each shortbread biscuit was placed in a Teflon vessel, followed by the addition of 7 mL of 65% HNO_3 and 1 mL of 35% (v/v) H_2O_2. The samples were subjected to microwave digestion using a Milestone SK 10 microwave oven. Post-digestion, the solutions were filtered through a 0.45 μm filter (Sartorius) and subsequently analyzed. The reported values represent the mean of three replicates.

2.2.6 | Determination of physical properties of shortbread biscuits

The baking loss was determined following the protocol described by Korese et al. (2021). Briefly, the weight of six shortbread biscuits randomly selected from each batch was measured before (W_1) and after baking (W_2). The percentage of baking loss was calculated using the following equation:

$$\text{Baking loss} = \frac{(W_2 - W_1) \times 100}{W_1} \quad (1)$$

The thickness (T) and diameter (D) of six baked shortbread biscuits of each batch were measured using a digital Vernier caliper (Mitutoyo Calipers) (AACC, 2000). The spread ratio was calculated by dividing diameter (D) by thickness (T) (Korese et al., 2021). The volume was calculated as follows:

$$\text{Volume } \left(\text{cm}^3\right) = \left(\pi T D^2\right)/4 \quad (2)$$

2.2.7 | Color analysis

The crust color of the controls and SPF-based shortbread biscuits was measured using a colorimeter (CR-410 Konica Minolta Inc.). After calibration of the instrument with a standard white plate, the L^*, a^*, and b^* color values of shortbread biscuits were recorded automatically.

2.2.8 | Textural analysis

The textural attributes of the shortbread biscuits were measured with a three-point bend test by using the TA-XT2 Texture Analyzer (Stable Micro Systems Ltd.) equipped with HDP/3 PB rig. The method proposed by Tarancón et al. (2014) was utilized with some modifications. The load cell was 5 kg, trigger force was set to 5 g, and the probe distance was set to 5 mm. Pre-set, test, and post-test speeds were adjusted to 1.0, 3.0, and 10.0 mm/s, respectively. The gap between the supports was 40 mm. In this test, the typical mean maximum force value (N) refers to hardness, whereas the mean distance compressed before breaking value refers to fracturability (mm). The analyses were performed in five replicates for each sample.

2.2.9 | In vitro glycemic index

In vitro glycemic index (GI) of shortbread biscuits was determined according to the method described by Aribas et al. (2020) with slight modifications. Briefly, a pepsin enzyme solution (5 mg/mL) prepared in 2 mL of 0.05 M HCl was added to 100 mg of ground shortbread biscuits weighed into 15 mL tubes. Then, the mixtures were incubated at 37°C in a shaking water bath for 30 min. Five milliliters of sodium acetate buffer (0.5 M) was added to the mixture to adjust the pH to 5.2. Then, enzyme mixtures (1 mL), consisting of 0.104 g of pancreatin and 14.45 U of amyloglucosidase and 25.43 U/mL of invertase, were added to the tubes and then incubated at 37°C in a shaking water bath (GFL 1083). The 100 μL of each sample were transferred to glass tubes at 0 and 90 min, and 1 mL of ethanol was added to stop the enzymatic activity. After the centrifugation of these mixtures for 10 min at 1000 × g (Hettich Universal 320 R), the glucose content was determined using GOPOD reagent. The absorbances were read using a spectrophotometer (Shimadzu UV-1800) adjusted to 510 nm. The ratio of the area under the hydrolysis curve for the sample to that of white bread, the reference sample, was used to calculate the hydrolysis index (HI), which shows the rate of starch digestion (Equation 3). The HI is the percentage of carbohydrates hydrolyzed over time, typically compared to a reference food (white bread). The following formula was used to calculate the estimated GI (Goñi et al., 1997):

$$\text{HI} = \frac{\text{Area under the hydrolysis curve for shortbreads}}{\text{Area under the hydrolysis curve for reference food}} \times 100 \quad (3)$$

$$\text{GI} = 39.71 + (0.549 \times \text{HI}) \quad (4)$$

where HI is hydrolysis index.

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 2 Proximate composition, energy, total polyphenol, and flavonoid content of shortbread biscuit samples.

	WB	SB	PSPB100	PSPB50	USPB100	USPB50
Moisture (%)	7.18 ± 0.39^{c}	3.70 ± 0.09^{d}	8.61 ± 0.26^{b}	7.456 ± 0.18^{c}	9.10 ± 0.13^{a}	7.41 ± 0.18^{c}
Ash (%)	0.92 ± 0.02^{d}	0.87 ± 0.03^{e}	1.77 ± 0.08^{a}	1.49 ± 0.03^{c}	1.99 ± 0.04^{a}	1.50 ± 0.04^{c}
Fat (%)	11.60 ± 0.40^{d}	15.00 ± 0.20^{c}	22.60 ± 1.00^{a}	21.50 ± 0.10^{b}	22.90 ± 0.50^{a}	21.00 ± 0.40^{b}
Protein (%)	8.33 ± 0.59^{a}	4.82 ± 0.02^{e}	6.62 ± 0.04^{c}	5.82 ± 0.36^{d}	7.67 ± 0.09^{b}	6.55 ± 0.08^{c}
Crude fiber (%)	2.98 ± 0.48^{c}	1.33 ± 0.61^{d}	5.11 ± 1.09^{b}	4.15 ± 0.58^{bc}	6.63 ± 0.93^{a}	4.54 ± 0.18^{b}
CHO (%)	68.99 ± 0.92^{b}	74.29 ± 0.29^{a}	55.29 ± 1.79^{d}	59.57 ± 1.00^{c}	51.71 ± 0.43^{e}	59.00 ± 0.08^{c}
Energy (kcal/100 g)	413.67 ± 2.29^{c}	451.44 ± 2.88^{a}	451.06 ± 2.02^{a}	455.09 ± 3.41^{a}	443.62 ± 6.56^{b}	451.22 ± 3.60^{a}
Polyphenols (mg GAE/100 g)	54.81 ± 2.48^{d}	33.05 ± 1.78^{f}	63.93 ± 1.67^{c}	46.24 ± 2.63^{e}	88.85 ± 0.67^{a}	75.30 ± 1.18^{b}

Note: The letters (a–f) are indications of the significance at $p < 0.05$ within each variable according to Duncan's test. CHO: carbohydrates; WB: wheat-based biscuits; SB: corn starch–based biscuits; PSPB100: biscuits made from peeled sweet potato flour; PSPB50: biscuits made from peeled sweet potato flour blended with corn starch (50%–50%); USPB100: biscuits made from unpeeled sweet potato flour; USPB50: biscuits made from unpeeled sweet potato flour blended with corn starch (50%–50%).

2.2.10 | Statistical analysis

The assays were performed three times ($n = 3$), and the results were expressed as mean ± standard deviation. One-way analysis of variance was used to compare the mean values, followed by Duncan's post hoc test ($p < 0.05$). All statistical analyses were performed using SPSS Statistic 20.0 software (SPSS Inc.). Principal component analysis (PCA) was conducted using Minitab 18.

3 | RESULTS AND DISCUSSION

3.1 | Proximate composition of shortbread biscuits

Moisture is a key factor that substantially impacts the shortbread biscuit quality and shelf life. The moisture of all shortbread biscuits (Table 2) was below 14%, which is acceptable for long-term storage of shortbread biscuits (Asadi et al., 2022). The shortbread biscuits made entirely from unpeeled SP flour (USPF) exhibited the highest water content, followed by those made with PSP flour (PSPF) ($p < 0.05$). This may be explained by the high-water-holding capacity of SP insoluble fibers as reported by a previous study (Belkacemi, 2022). Those prepared from these flours mixed with corn starch recorded a moisture comparable to that of wheat flour–based shortbread biscuits ($p > 0.05$), whereas shortbread biscuits made entirely from corn starch have a very low moisture content of less than 5%. Low moisture content of shortbread biscuits results in organoleptic qualities characterized by dryness or crispness (Cauvain & Young, 2008), as confirmed later by textural analysis. The ash content (Table 2) of shortbread biscuits was improved by substituting wheat flour with USPF or PSPF, used either entirely or mixed at 50% with corn starch. Their contents in USPB and PSPB batches were approximately twofold higher than that recorded for wheat shortbread biscuits. It is well reported that the ash content in SPF is greater than that reported in soft wheat flour (Chikpah et al., 2020; Olatunde et al., 2019). Regardless of whether PSPFs or USPFs were used, the shortbread biscuits made from these flours displayed the highest fat content ($p < 0.05$). This high fat content was likely due to the high oil absorption capacity of SPFs (Belkacemi, 2022), probably preventing the leaching of fat during baking. This high oil absorption capacity in SPF could be attributed to blanching, which enhances the exposure of proteins, allowing them to interact more effectively with oil due to the micro-porous nature of the blanched product (Ohizua et al., 2017). In addition, the higher level of crude fibers in SPF-added shortbread biscuits may be the main reason for higher oil binding. Crude fiber, particularly insoluble fiber, has a porous and rough structure, increasing the surface area available for oil binding; hence, more fiber content leads to more oil retention due to capillary action and physical entrapment (Elleuch et al., 2011). The oil absorption capacity parameter is important in determining the flour's ability to absorb fat during product processing. Fat gives shortbread biscuits a soft and crisp texture and affects their sensorial properties (Liu et al., 2022). The fat content in SP-based shortbread biscuits was comparable to that reported by Okpala and Ofoedu (2018) and Giri and Sakhale (2019) but higher than that stated by Adeyeye and Akingbala (2015) and Laelago et al. (2015). Even though protein content was lower in SP-based shortbread biscuits compared to wheat-based ones (Table 2), nevertheless, it is worthy of mentioning that SP proteins are of high quality. In fact, SP proteins, of which sporamin represents approximately 80% of total proteins, are health-promoting because of their biofunctional benefits (Habinshuti et al., 2021), including antioxidant activity, decreasing

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

triglyceridemia, anticancer, and antiproliferative effects (Elkatry et al., 2023). The protein content in SP-based shortbread biscuits is comparable to that reported for OFSP cookies (Laelago et al., 2015). Incorporating corn starch into USPF at a rate of 50% reduced the protein content ($p < 0.05$), which is due to the dilution effect produced by the corn starch due to its low protein content. Moreover, the lowest protein content was recorded in the CS-based shortbread biscuits. As expected, the highest crude fiber content was exhibited by USPB than PSPB, which had around twice the crude fiber value ($p < 0.05$) in shortbread biscuits made from wheat flour (Table 2). Shaari et al. (2021) suggested that unpeeling is the best way to preserve the fiber content of SP for good health. The fiber content in SP-based shortbread biscuits was higher than that reported in SPFs (Belkacemi, 2022). It seems that baking increased crude fiber values, which could be attributed to their release during cooking, making them more available for analysis (Matthee & Appledorf, 1978). The lowest carbohydrate content was recorded in shortbread biscuits made from USPF. The primary reason for this observation is attributed to high fiber and ash content. Overall, the carbohydrate content of SP-based shortbread biscuits, used at 100% or 50%, remains slightly ($p < 0.05$) lower compared to wheat-based shortbread biscuits, probably because of the higher starch content in wheat flour as stated by Adeyeye and Akingbala (2015). The highest total energy (Table 2) was displayed by the four SP shortbread biscuits made from either PSPF, corn starch, or those made from the mixture (USPB50 and PSPB50) ($p > 0.05$). Despite their high carbohydrate content, wheat flour–based shortbread biscuits recorded a lower energy value compared to USPF-based shortbread biscuits. The high-fat content of USPB increased their energy density. Laelago et al. (2015) reported that the increment of the crude fat content outweighs the decrease in carbohydrate content in OFSP cookies.

3.2 | Total polyphenol content of shortbread biscuits

Apart from their importance for health, polyphenols may play an important role in food characteristics by influencing sensorial and physicochemical features such as bitterness, color, flavor, and odor (Arzola-Rodríguez et al., 2022). For all shortbread biscuits, the polyphenol content varied between 33.05 ± 1.71 and 88.85 ± 0.66 mg GAE/100 g dry matter, with the highest content ($p < 0.05$) recorded in the shortbread biscuits made from USPF (Table 2). The substitution of wheat flour by USP increased the TPC of the shortbread biscuits by almost 50%. Keeping SP peel during flour processing serves not only as a potential source of fibers but also as a source of phenolic compounds, which are well known for their antioxidant properties, promoting health and reducing disease risk. The polyphenol content of SPF-based shortbread biscuits was slightly higher than that of SPF (Belkacemi, 2022). Heat treatment releases the phenolic acids bound to the cell walls, which improves their bioavailability (Nakov et al., 2020). Besides, certain products formed as a result of the Maillard reaction and having a reductone structure could also contribute to an increase in phenolic content (Mitrović et al., 2021). Blending corn starch with USPF resulted in reducing polyphenol content in the corresponding shortbread biscuits, which nevertheless remains higher than that recorded for wheat-based shortbread biscuits and even shortbread biscuits made entirely with PSPF ($p < 0.05$).

3.3 | Mineral composition

Mineral analysis showed significant differences among shortbread biscuit samples (Table 3). The outcomes of this study revealed the presence of most assessed minerals in higher concentrations in SP-based cookies than in wheat-based ones. The presence of a significant amount of minerals in SP-based shortbread biscuits reflects their flour richness in these micronutrients. This richness could be explained by the availability of minerals and their uptake from soil (Mitiku et al., 2018). The major minerals in all SP-based shortbreads were sodium and phosphorus, followed by potassium, calcium, and magnesium, whereas iron and zinc were the minor ones. These findings do not correspond to those of Olatunde et al. (2019) and Ohizua et al. (2017), who found potassium or magnesium as the main minerals in SPF, respectively. Most of the mineral contents in the present study were less than those reported for OFSP-based cookies (Kolawole et al., 2020). This variability is attributed to the difference in cultivars, soil type, climate, and geographical location (Boni et al., 2018; Sanoussi et al., 2016). Calcium, sodium, and phosphorus contents were comparable between shortbreads made from 100% USPF and those from 100% PSPF, indicating that these minerals are present in SP flesh rather than its peels. However, the remaining minerals, particularly potassium and iron, were more concentrated in 100% USPF-based shortbreads. This affirms that potassium, magnesium, iron, and zinc are more prevalent in SP skin, which is in agreement with the study of Dako et al. (2016). Magnesium, iron, and zinc are important cofactors of certain enzymes and are involved in numerous biochemical pathways (Huskisson et al., 2007). Therefore, removing the SP peel greatly reduces its nutritional value. Overall, the mineral content of shortbread biscuits made with SPF alone or mixed with starch was significantly

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 3 Mineral composition of the shortbread biscuits.

Minerals	WB	SB	PSPB100	PSPB50	USPB100	USPB50
Sodium (%)	0.20 ± 0.000^{c}	0.18 ± 0.01^{d}	0.29 ± 0.09^{a}	0.21 ± 0.01^{c}	0.29 ± 0.01^{a}	0.23 ± 0.03^{b}
Potassium (mg/100 g)	65.59 ± 0.165^{c}	14.69 ± 0.55^{f}	73.61 ± 1.90^{b}	53.46 ± 0.36^{e}	118.75 ± 3.55^{a}	60.28 ± 0.13^{d}
Phosphorus (%)	0.54 ± 0.01^{a}	0.43 ± 0.01^{c}	0.54 ± 0.01^{a}	0.43 ± 0.01^{c}	0.54 ± 0.01^{a}	0.47 ± 0.00^{b}
Magnesium (mg/100 g)	7.60 ± 0.142^{e}	3.84 ± 0.01^{f}	28.49 ± 0.40^{b}	14.88 ± 0.29^{d}	32.67 ± 0.78^{a}	17.60 ± 0.54^{c}
Calcium (mg/100 g)	18.70 ± 0.330^{e}	25.36 ± 0.29^{d}	201.05 ± 3.45^{a}	98.88 ± 0.42^{c}	204.75 ± 7.25^{a}	115.20 ± 2.50^{b}
Iron (mg/100 g)	0.77 ± 0.049^{d}	0.62 ± 0.01^{d}	2.27 ± 0.06^{b}	1.35 ± 0.14^{c}	4.16 ± 0.41^{a}	2.28 ± 0.01^{b}
Zinc (mg/100 g)	0.40 ± 0.009^{e}	0.40 ± 0.05^{e}	2.63 ± 0.09^{b}	0.67 ± 0.01^{d}	2.92 ± 0.03^{a}	1.20 ± 0.09^{c}

Note: The letters (a–f) are indications of the significance at $p < 0.05$ within each variable according to Duncan's test. WB: wheat-based biscuits; SB: corn starch–based biscuits; PSPB100: biscuits made from peeled sweet potato flour; PSPB50: biscuits made from peeled sweet potato flour blended with corn starch (50%–50%); USPB100: biscuits made from unpeeled sweet potato flour; USPB50: biscuits made from unpeeled sweet potato flour blended with corn starch (50%–50%).

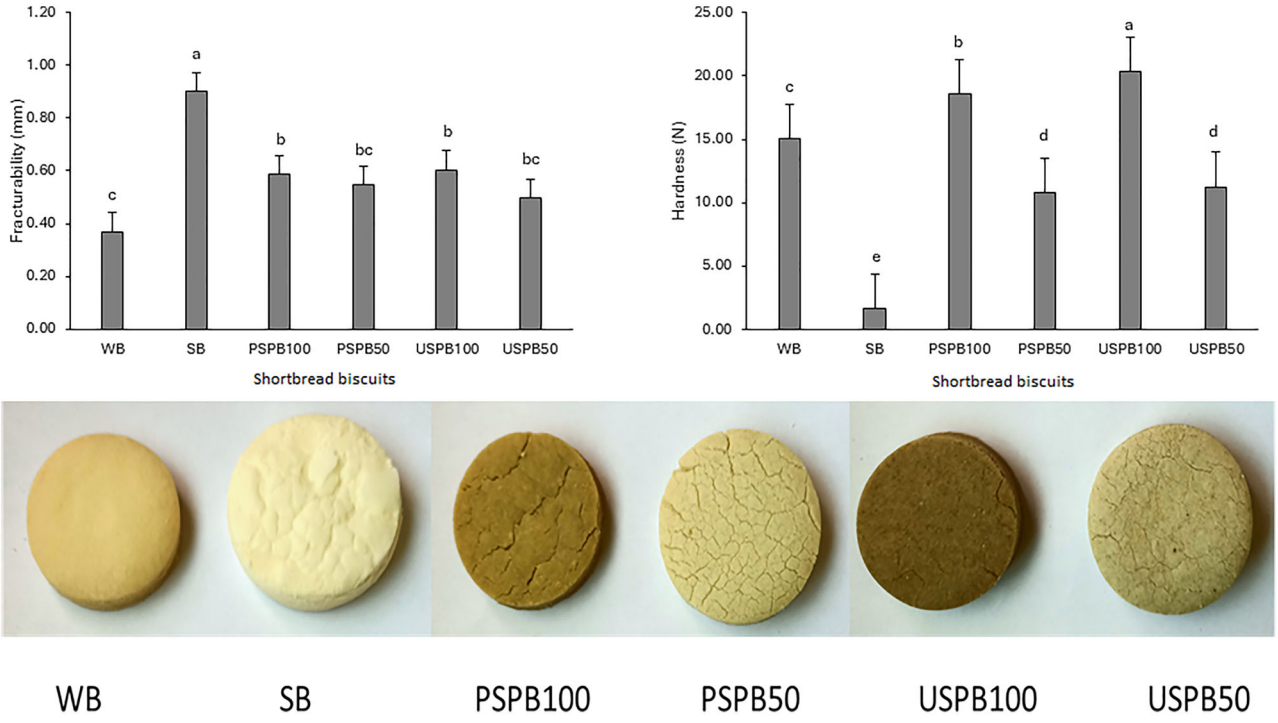


FIGURE 1 Textural properties and images of the shortbread biscuit shortbread biscuits (WB: wheat-based shortbread biscuits; SB: corn starch–based shortbread biscuits; PSPB100: shortbread biscuits made from peeled sweet potato flour; PSPB50: shortbread biscuits made from peeled sweet potato flour blended with corn starch [50%–50%]; USPB100: shortbread biscuits made from unpeeled sweet potato flour; USPB50: shortbread biscuits made from unpeeled sweet potato flour blended with corn starch [50%–50%]).

higher ($p < 0.05$) than that of wheat-based shortbread biscuits, which makes their consumption nutritionally advantageous.

3.4 | Color parameters

As it appears visually in Figure 1, both PSP- and USP-based shortbread biscuits had brown crust color compared to the light color of wheat- and starch-based shortbread biscuits or those prepared from blended flours. The crust color is related principally to the Maillard and caramelization reactions. The β-carotene pigment naturally present in SP flesh and skin (Truong et al., 2018) could darken the shortbread biscuit's crust color. Moreover, the USP-based biscuit exhibited much higher redness (a^*) compared to other shortbread biscuits (Table 4). A previous study (Belkacemi, 2022) showed that flour from unpeeled SP displayed the highest a^* value, which is due to the presence of carotenoids (Ameny & Wilson, 1997). Besides, the high amount of ash in these shortbread biscuits could contribute to their darker color. In this regard, Czaja et al.

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 4 Physical parameters and color attributes of shortbread biscuits.

	WB	SB	PSPB100	PSPB50	USPB100	USPB50
Baking loss (%)	11.91 ± 0.44^{a}	11.92 ± 0.63^{a}	7.73 ± 0.93^{d}	10.26 ± 0.56^{b}	8.61 ± 0.33^{c}	10.07 ± 0.65^{b}
Volume (cm^3)	12.50 ± 0.59^{b}	14.48 ± 1.13^{a}	9.05 ± 0.95^{c}	9.44 ± 0.88^{c}	8.51 ± 0.52^{c}	8.96 ± 0.65^{c}
Spread ratio	5.21 ± 0.38^{b}	5.87 ± 0.21^{a}	4.76 ± 0.32^{c}	4.94 ± 0.20^{bc}	4.85 ± 0.18^{bc}	4.98 ± 0.35^{bc}
Color attributes						
L*	82.61 ± 0.23^{b}	86.36 ± 0.62^{a}	64.27 ± 0.57^{e}	77.62 ± 0.01^{c}	57.52 ± 0.47^{f}	70.49 ± 0.65^{d}
a*	-2.97 ± 0.04^{d}	-4.18 ± 0.03^{e}	-0.42 ± 0.03^{b}	-2.55 ± 0.13^{c}	1.41 ± 0.26^{a}	-0.24 ± 0.05^{b}
b*	29.80 ± 0.17^{b}	26.21 ± 0.45^{c}	32.24 ± 0.60^{a}	30.10 ± 0.66^{b}	25.83 ± 0.20^{c}	23.37 ± 0.42^{d}

Note: The letters (a–e) are indications of the significance at $p < 0.05$ within each variable according to Duncan's test. WB: wheat-based biscuits; SB: corn starch–based biscuits; PSPB100: biscuits made from peeled sweet potato flour; PSPB50: biscuits made from peeled sweet potato flour blended with corn starch (50%–50%); USPB100: biscuits made from unpeeled sweet potato flour; USPB50: biscuits made from unpeeled sweet potato flour blended with corn starch (50%–50%).

(2020) stated that high ash content darkens the color of products. However, mixing SPF with corn starch lightened the shortbread biscuits, reducing their a^* and b^* values. According to Liu et al. (2022), the addition of starch lightens the color of shortbread biscuits, whereas it decreases the redness and yellowness.

3.5 | Physical characteristics of shortbread biscuits

The baking loss, spread ratio, and volume results of the control shortbread biscuits and SP-based shortbread biscuits are reported in Table 4. These parameters, strongly impacted by both ingredients and production processes, establish the dimensions and form of the biscuit, thereby shaping consumer preferences. The shortbread biscuits made from 100% PSPF and USPF presented the lowest baking loss and volume compared to control shortbread biscuits prepared from wheat flour or corn starch ($p < 0.05$). This is in agreement with the study of Korese et al. (2021), reporting less baking loss in cookies prepared from peeled and unpeeled OFSP-based flours. These low physical parameter values could be attributed to the fibers contained in USPF and PSPF contributing to reducing moisture loss during baking and negatively affecting the volume of corresponding shortbread biscuits. According to Kuchtová et al. (2018), the decrease in biscuit volume is due to fibers that damage dough structure and decrease CO_2 gas retention in the dough matrix, which is in agreement with the present outcomes. The calculation of spread ratio revealed lower ratios for all SPF-based shortbread biscuits compared to shortbread biscuits made from wheat flour and 100% corn starch ($p < 0.05$). Higher fiber content and the high-water-holding capacity of SPF interfere with biscuit spreading (Jemziya & Mahendran, 2015). Thongram et al. (2016) stated that the hydrophilic nature of the flour results in a decrease in the spread ratio of cookies. At this fact, it is reported that high-water-holding capacity reduces sugar availability to dissolve and thereby leads to a decrease in spread ratio (Giri & Sakhale, 2019). However, it is worth mentioning that using icing sugar in the present study instead of sugar crystals may have reduced the spread ratio difference between wheat-controlled shortbread biscuits and those made from SPF, probably because icing sugar dissolves rapidly during dough making and baking. The starch-based shortbread biscuits displayed the highest spread ratio, which is in agreement with the study of Sogabe et al. (2021) reporting a larger expansion occurring in the starch-based cookies.

3.6 | Textural properties of shortbread biscuits

Starch-based shortbread biscuits showed a very small hardness value, whereas the highest hardness value ($p < 0.05$) was recorded for shortbread biscuits made from 100% USPF (20.32 ± 2.00 N) than those with peeled ones (18.55 ± 0.97 N) (Figure 1). This finding is consistent with those of Korese et al. (2021), who found a higher hardness of shortbread biscuits made from OFSP flour compared to the control ones made entirely with wheat flour. The hardness of PSPB100 and USPB100 remains much less than that reported by Korese et al. (2021). In their study, the authors used whole eggs, including egg whites, known to significantly harden biscuit texture. The high breaking strength could be due to the presence of fibers and their nature, especially those of SP skin. According to Laguna et al. (2014), the larger the fiber size, the higher the strength required to break the biscuit. Besides, variations in protein type and the way they interact with starch components to form a dough matrix explain variations in biscuit hardness (Mais & Brennan, 2008). Overall, blending SPFs with corn starch resulted in a concomitant increase in weight loss and volume and a considerable decrease in the strength required to break the shortbread biscuits PSB50 (10.76 ± 0.74 N) and USP50 (11.24 ± 0.22 N). The reduction

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

in biscuit hardness of these shortbread biscuits is related to the substitution of half SPF with corn starch, which likely produced an airier matrix and hence led to a weakening of SP biscuit structure. In this regard, it has been reported that using starch to prepare cookies results in a highly porous structure, requiring thereby a lower fracture force (Sogabe et al., 2021). Moreover, the starch-based shortbread biscuits had the highest fracturability (0.90 ± 0.15 mm), testifying to their fragility (Figure 1). The fracturability of a cookie represents its deformation until it breaks during compression (Boz, 2019). This textural parameter is interrelated to the crispiness of the cookies (Hussain et al., 2022). Starch-based shortbread biscuits were crumbly and easily broken. Furthermore, the lesser moisture of corn starch-based shortbread biscuits contributed to their crispness. Conforti et al. (2012) reported that dough in which part of the wheat flour was replaced by corn starch could lose water more rapidly. Mixing PSPF or USPF with corn starch affected the texture of the shortbread biscuits by making them less brittle than the corresponding 100% SP-based shortbread biscuits.

TABLE 5 Loading coordinates of first two principle components.

Variable	PC1	PC2
Moisture	−0.293	0.158
Ash	−0.282	−0.142
Fat	−0.242	−0.252
Protein	−0.153	0.322
Crude fiber	−0.298	−0.054
Carbohydrate	0.298	0.074
Polyphenol	−0.261	−0.136
Baking loss	0.255	0.074
Hardness	−0.252	0.234
Fracturability	0.160	−0.365
Spread ratio	0.295	−0.137
Glycemic index	0.293	−0,149
Flavonoids	0.059	−0.461
Volume	0.288	0.079
L^*	0.204	0.222
a^*	−0.225	−0.230
b^*	0.025	0.454

3.7 | Estimated glycemic index

Generally, cereal-based gluten-free foods have a high GI (Giuberti & Gallo, 2017), and the replacement of rice or maize with other gluten-free raw ingredients is of interest to researchers to reduce the GI of gluten-free foods and, consequently, the incidence of metabolic disorders. SP tubers are well recognized as having a low or middle GI (Foster-Powell et al., 2002). This later depends on the cultivar (Foster-Powell et al., 2002) and mostly on cooking methods, which increase its GI (Allen et al., 2012; Astawana & Widowa, 2011). In the present study, incorporating SPF resulted in a relative improvement in the GI of shortbread biscuits (Figure 2) compared to those made with wheat flour (92.02 ± 0.05) and corn starch (99.97 ± 0.64). However, all four SP shortbread biscuits still fall into the high GI category (>70). Despite the low/middle GI of the raw SP tuber, it is reported that baking increases it considerably up to 80 (Astawana & Widowa, 2011) and even >90 in some cultivars (Bahado-Singh et al., 2011). Besides, the foods' GI did not depend only on raw material and processing methods but also on other ingredients, such as sugars, protein, and fat, among others (Reyes-Pérez et al., 2013). Regardless of the 50% corn starch incorporation, the GIs of USPB50 (89.75 ± 0.42) and PSPB50 (88.77 ± 0.30) are comparable ($p > 0.05$) to those of shortbread biscuits made solely from USPF and PSPF. It is possible that the high-fat content in these shortbread biscuits interferes with the in vitro enzymatic digestion of starch. At this fact, Menon et al. (2015) reported that starch–lipid complexes could limit the digestion of starch by restricting its swelling.

3.8 | Principal component analysis (PCA)

PCA was utilized to determine the relationships among the variables of SP-incorporated muffins. The first two principal components (PC1 and PC2) accounted for 78.3% of the total variability in the studied parameters, with PC1 and PC2 contributing 62.8% and 15.4% of the variance, respectively. The loading values of these principal components are presented in Table 5. PC1 was predominantly influenced by GI (0.293), moisture (−0.293), crude fiber (−0.298), spread ratio (0.295), volume (0.288), and ash content (−0.282). In contrast, PC2 was primarily associated with flavonoid content (−0.461), b^* value (0.454), fracturability (−0.365), and protein content (0.322). The score plot (Figure 3a) visually represents the grouping of shortbread biscuits based on their similarities. PSPB and USPB, positioned near the y-axis on the left side of the plot, exhibited higher levels of crude fiber, moisture, polyphenols, ash, a^* value, hardness, and fat content. Additionally, USPB shortbread biscuits were distinct from PSPB biscuits due to their elevated crude fiber, polyphenol, ash, a^*, and fat values. Conversely, SB was located at the far-right side of the plot, characterized by the highest GI, spread ratio, and fracturability. Meanwhile, WB was positioned at a considerable distance from both SB and SP-incorporated biscuits, primarily due to its high b^* and protein values

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

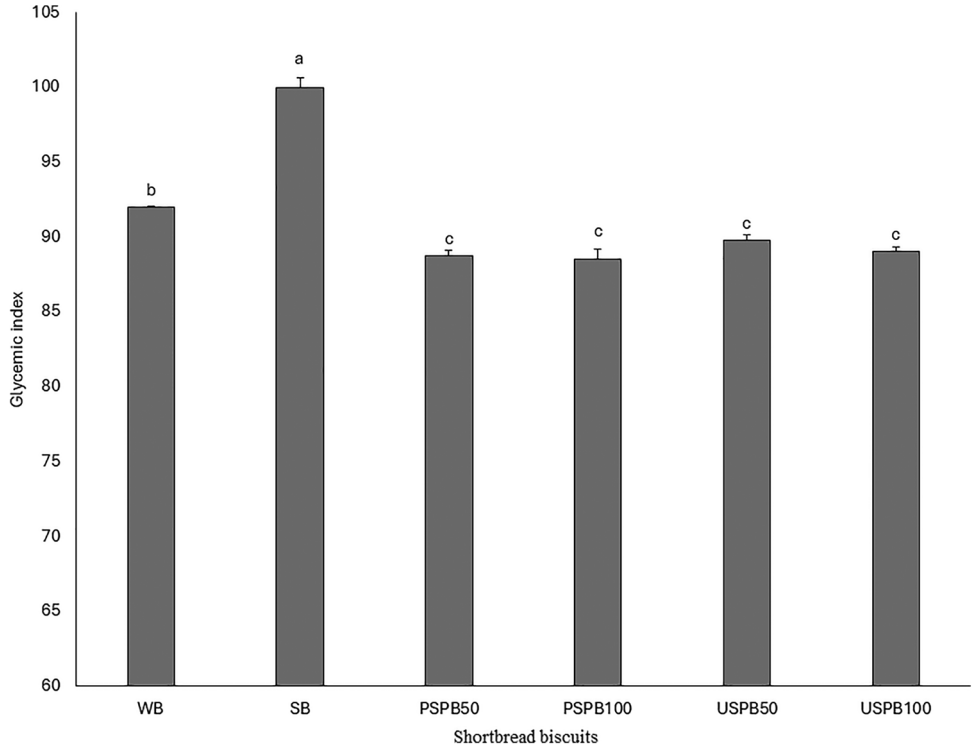


FIGURE 2 Estimated glycemic index values of the shortbread biscuit shortbread biscuits (WB: wheat-based shortbread biscuits; SB: corn starch–based shortbread biscuits; PSPB100: shortbread biscuits made from peeled sweet potato flour; PSPB50: shortbread biscuits made from peeled sweet potato flour blended with corn starch [50–50]; USPB100: shortbread biscuits made from unpeeled sweet potato flour; USPB50: shortbread biscuits made from unpeeled sweet potato flour blended with corn starch [50–50]).

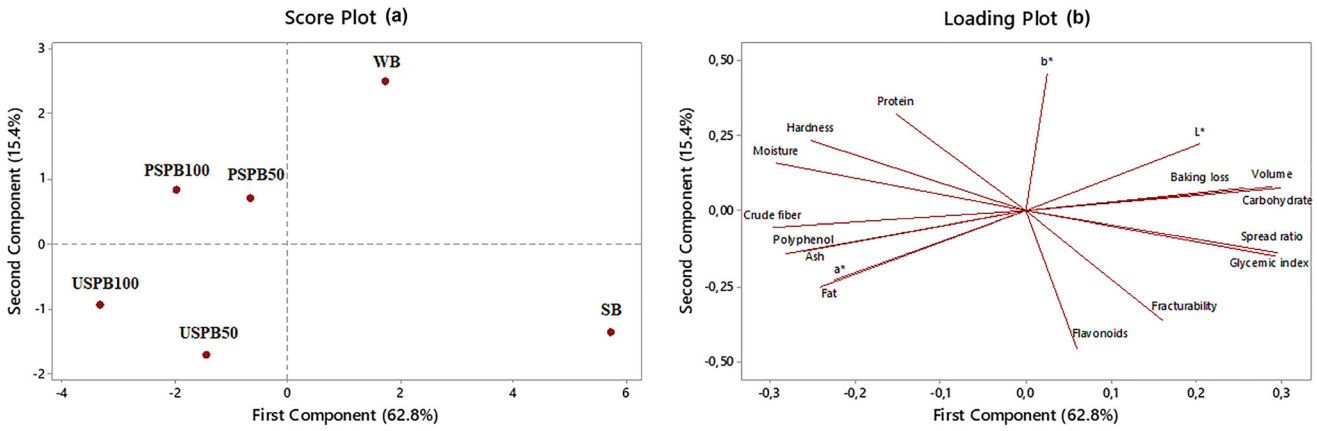


FIGURE 3 Score plot (a) and loading plot (b) corresponding to the first two principal components from the analysis of shortbread biscuit properties.

along PC2. The loading plot (Figure 3b) provides an overall perspective on the interrelationships among the studied parameters. Variables positioned in proximity indicate a strong positive correlation, whereas those placed in opposite directions suggest a negative correlation. Specifically, crude fiber, polyphenol, ash, a^*, and fat values were closely clustered, signifying a positive correlation among them. Furthermore, baking loss, volume, carbohydrate content, spread ratio, and GI were grouped together on the right side of PC1, reflecting their positive correlation. However,

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

these parameters were negatively correlated with polyphenol content, ash, crude fiber, a^*, and fat, as indicated by their opposite positioning in the plot.

4 | CONCLUSION

Substituting wheat flour with SPF offers a promising approach to enhancing the nutritional quality of shortbread biscuits. Replacing soft wheat flour with both PSPF and USPF improves proximate composition, polyphenol, and flavonoid content. In particular, USPF enriched the shortbread biscuits remarkably in terms of mineral and fiber amounts. Moreover, PSP and USP enrichment led to a reduction in estimated GI values, making these shortbread biscuits a potentially healthier option. Blending these flours with 50% corn starch when producing gluten-free shortbread biscuits (PSPB50 and USPB50) yielded not only improved nutritional quality but also favorable textural properties, yet optimizing ingredient ratios to balance nutrition with sensory quality remains an area for future research. Moreover, although PSP and USP enrichment contributed to a lower estimated GI, in vivo glycemic response studies are necessary to confirm these effects in human subjects. Despite these limitations, PSP and USP-enriched shortbread biscuits present a promising option for individuals with gluten intolerance and those following a health-conscious diet.

AUTHOR CONTRIBUTIONS

Louiza Belkacemi: Conceptualization; data curation; formal analysis; writing—original draft. **Muhammed Ozgolet**: Data curation; formal analysis; review and editing. **Muhammet Arici**: Validation; review and editing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

The manuscript has no ethical issues.

ORCID

Muhammed Ozgolet https://orcid.org/0000-0001-5584-097X
Muhammet Arici https://orcid.org/0000-0003-4126-200X

REFERENCES

Adeyeye, S. A., & Akingbala, J. O. (2015). Quality characteristics and acceptability of cookies from sweet potato-maize flour blends. *Nutrition and Food Science*, *45*(5), 703–715. https://doi.org/10.1108/NFS-03-2015-0020

Allen, J. C., Corbitt, A. D., Maloney, K. P., Butt, M. S., & Truong, V. (2012). Glycemic index of sweet potato as affected by cooking methods. *The Open Nutrition Journal*, *6*, 1–11. https://doi.org/10.2174/1874288201206010001

Ameny, M. A., & Wilson, P. W. (1997). Relationship between hunter color values and beta-carotene content in white-fleshed African sweet potatoes (*Ipomoea batatas* Lam). *Journal of the Science Food and Agriculture*, *73*(3), 301–306. https://doi.org/10.1002/(SICI)1097-0010(199703)73:3⟨301::AID-JSFA726⟩3.0.CO;2-Z

American Association of Cereal Chemists. (2000). *Approved methods of the AACC, 10th ed*. American Association of Cereal Chemists.

Association of Official Agricultural Chemists—AOAC. (2010). *Official methods of analysis of association of official analytical chemists* (18th ed.). AOAC.

Aribas, M., Kahraman, K., & Koksel, H. (2020). In vitro glycemic index, bile acid binding capacity and mineral bioavailability of spaghetti supplemented with resistant starch type 4 and wheat bran. *Journal of Functional Foods*, *65*, 103778. https://doi.org/10.1016/j.jff.2020.103778

Arzola-Rodríguez, S. I., Muñoz-Castellanos, L. N., López-Camarillo, C., & Salas, E. (2022). Phenolipids, amphipilic phenolic antioxidants with modified properties and their spectrum of applications in development: A Review. *Biomolecule*, *12*(12), 1897. https://doi.org/10.3390/biom12121897

Asadi, S. Z., Ali Kha, M., & Zaid, S. A. (2022). Study on the shelf life of cookies incorporated with sapota and beetroot leaf powders. *Journal of Food Science and Technology*, *59*(10), 3848–3856. https://doi.org/10.1007/s13197-022-05408-1

Astawana, M., & Widowa, S. (2011). Evaluation of nutrition and glycemic index of sweet potatoes and its appropriate processing to hypoglycemic foods. *Indonesian Journal of Agricultural Science*, *12*(1), 40–46. https://doi.org/10.21082/ijas.v12n1.2011.p40-46

Ayeleso, T. B., Ayeni, P. O., Ayeleso, A. O., Ramachela, K., & Mukwevho, E. (2024). Nutritional and chemical constituents of different cultivars of sweet potato (*Ipomoea batatas* L.) grown in South Africa. *Tropical Journal of Natural Product Research*, *8*(2), 6100–6107. https://doi.org/10.26538/tjnpr/v8i2.7

Bahado-Singh, P. S., Riley, C. K., Wheatley, A. O., & Lowe, A. I. C. (2011). Relationship between processing method and the glycemic indices of ten sweet potato (*Ipomoea batatas*) cultivars commonly consumed in Jamaica. *Journal of Nutrition and Metabolism*, *2011*, 584832. https://doi.org/10.1155/2011/584832

Belkacemi, L. (2022). Blanching effect on physicochemical and functional properties of flours processed from peeled and unpeeled white-fleshed sweet potato Algerian cultivar. *Food Science and Technology, Campinas*, *42*, e86821. https://doi.org/10.1590/fst.86821

Boni, V. W. T., Digbeu, Y. D., Gbakayoro, J. B., Binaté, S., & Dué, E. A. (2018). Proximate and mineral composition and some anti-nutritional factors of flour from five improved sweet potato (*Ipomoea batatas*). *European Journal of Pharmaceutical and Medical Research*, *5*(11), 126–137.

Boz, H. (2019). Effect of flour and sugar particle size on the properties of cookie dough and cookie. *Czech Journal of Food Sciences*, *37*(2), 120–127. https://doi.org/10.17221/161/2017-CJF

de Camargo, A. C., Vidal, C. M., Canniatti-Brazaca, S. G., & Shahidi, F. (2014). Fortification of cookies with peanut skins: Effects on the composition, polyphenols, antioxidant properties, and sensory quality. *Journal of Agricultural and Food Chemistry*, *46*, 11228–11235. https://doi.org/10.1021/jf503625p

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Cauvain, S. P., & Young, L. S. (2008). *Bakery food manufacture and quality: Water control and effects*. A John Wiley and Sons Publication. https://doi.org/10.1002/9781444301083

Chikpah, S. K., Korese, J. K., Hensel, O., & Sturm, B. (2020). Effect of sieve particle size and blend proportion on the quality properties of peeled and unpeeled orange fleshed sweet potato composite flours. *Foods*, *9*, 740. https://doi.org/10.3390/foods9060740

Chuango, K., Julianti, E., & Ginting, S. (2019). Effect of pre-treatment in the making of purple-fleshed sweet potato flour towards cake characteristics. *IOP Conference Series: Earth and Environmental Science*, *260*, 1–7. https://doi.org/10.1088/1755-1315/260/1/012090

Conforti, P. A., Yamul, D. K., & Lupano, C. E. (2012). Influence of milk, corn starch, and baking conditions on the starch digestibility, gelatinization, and fracture stress of biscuits. *Cereal Chemistry*, *89*(4), 205–210. http://doi.org/10.1094/CCHEM-11-11-0138

Czaja, T., Sobota, A., & Szostak, R. (2020). Quantification of ash and moisture in wheat flour by Raman spectroscopy. *Foods*, *9*(3), 280. https://doi.org/10.3390/foods9030280

Dako, E., Retta, N., & Desse, G. (2016). Comparison of three sweet potato (*Ipomoea batatas* (L.) Lam) varieties on nutritional and anti-nutritional factors. *Global Journal of Science Frontier Research: D Agriculture and Veterinary*, *16*(4), 63–72.

Elkatry, H. O., El-Beltagi, H. S., Ramadan, K. M. A., Ahmed, A. R., Mohamed, H. I., Al-Otaibi, H. H., & Mahmoud, M. A. A. (2023). The chemical, rheological, and sensorial characteristics of Arabic bread prepared from wheat-orange sweet potatoes flour or peel. *Foods*, *12*(8), 1658. https://doi.org/10.3390/foods12081658

Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C., & Attia, H. (2011). Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food Chemistry*, *124*(2), 411–421. https://doi.org/10.1016/j.foodchem.2010.06.077

Foster-Powell, K., Holt, S. H. A., & Brand-Miller, J. C. (2002). International table of glycemic index and glycemic load values. *The American Journal of Clinical Nutrition*, *76*, 5–56. https://doi.org/10.1093/ajcn/76.1.5

Giri, N. A., & Sakhale, B. K. (2019). Development of sweet potato flour based high protein and low-calorie gluten free cookies. *Current Research in Nutrition and Food Science*, *7*(2), 427–435. https://doi.org/10.12944/CRNFSJ.7.2.12

Giuberti, G., & Gallo, A. (2017). Reducing the glycaemic index and increasing the slowly digestible starch content in gluten-free cereal-based foods: A review. *International Journal of Food Science and Technology*, *53*(1), 50–60. https://doi.org/10.1111/ijfs.13552

Goñi, I., Garcia-Alonso, A., & Saura-Calixto, F. (1997). A starch hydrolysis procedure to estimate glycemic index. *Nutrition Research*, *17*(3), 427–437. https://doi.org/10.1016/S0271-5317(97)00010-9

Habinshuti, I., Mu, T. H., & Zhang, M. (2021). Structural, antioxidant, aroma, and sensory characteristics of Maillard reaction products from sweet potato protein hydrolysates as influenced by different ultrasound-assisted enzymatic treatments. *Food Chemistry*, *361*, 130090. https://doi.org/10.1016/j.foodchem.2021.130090

Huskisson, E., Maggini, S., & Ruf, M. (2007). The Role of vitamins and minerals in energy metabolism and well-being. *Journal of International Medical Research*, *35*, 277–298. https://doi.org/10.1177/147323000703500301

Hussain, S., Alamri, M. S., Mohamed, A. A., Ibraheem, M. A., Qasem, A. A. A., Shamlan, G., & Ababtain, I. A. (2022). Dough performance and quality evaluation of cookies prepared from flour blends containing Cactus (*Opuntia ficus-indica*) and Acacia (*Acacia seyal*) gums. *Molecules (Basel, Switzerland)*, *27*(21), 7217. https://doi.org/10.3390/molecules27217217

Jemziya, M. B. F., & Mahendran, T. (2015). Quality characteristics and sensory evaluation of cookies produced from composite blends of sweet potato (*Ipomoea batatas* L.) and wheat (*Triticum aestivum L.*) flour. *Sri Lanka Journal of Food and Agriculture*, *1*(2), 23–30. https://doi.org/10.4038/sljfa.v1i2.16

Julianti, E., Lubis, Z., & Limanto, S. (2019). Utilization of purple sweet potato flour, starch, and fibre in biscuits making. In International Conference on Food and Bio-Industry. 2019 *IOP Conf. Series: Earth and Environmental Science* (pp. 443). IOP Publishing. https://doi.org/10.1088/1755-1315/443/1/012047

Kolawole, F., Akinwande, B. A., Ade-omowaye, B. I. O., Azeez, S. O., & Oyeyinka, S. A. (2021). Amino acid, phytochemicals, and antioxidant activities of gluten-free cookies from orange-fleshed sweet potato and pleurotus tuber-regium sclerotium. *Annals of the University Dunarea de Jos of Galati. Fascicle VI : Food Technology*, *45*(2), 20–32. https://doi.org/10.35219/foodtechnology.2021.2.02

Kolawole, F. L., Akinwande, B. A., & Ade-Omoway, B. I. O. (2020). Physicochemical properties of novel cookies produced from orange-fleshed sweet potato cookies enriched with sclerotium of edible mushroom (*Pleurotus tuberregium*). *Journal of the Saudi Society of Agricultural Sciences*, *19*, 174–178. https://doi.org/10.1016/j.jssas.2018.09.001

Korese, J. K., Chikpah, S. K., Hensel, O., Pawelzik, E., & Sturm, B. (2021). Effect of orange-fleshed sweet potato four particle size and degree of wheat four substitution on physical, nutritional, textural and sensory properties of cookies. *European Food Research and Technology*, *247*, 889–905. https://doi.org/10.1007/s00217-020-03672-z

Krajewska, A., & Dziki, D. (2023). Physical properties of biscuits enriched with fruits and their byproducts. *International Agrophysics*, *37*, 245–264. https://doi.org/10.31545/intagr/165803

Kuchtová, V., Kohajdová, Z., Karovičová, J., & Lauková, M. (2018). Physical, textural and sensory properties of cookies incorporated with grape skin and seed preparations. *Polish Journal of Food and Nutrition Sciences*, *68*(4), 309–317. https://doi.org/10.2478/pjfns-2018-0004

Laelago, T., Haile, A., & Fekadu, T. (2015). Production and quality evaluation of cookies enriched with β-carotene by blending orange-fleshed sweet potato and wheat flours for alleviation of nutritional insecurity. *International Journal of Food Sciences and Nutrition*, *5*(5), 209–217. https://doi.org/10.5923/j.food.20150505.05

Laguna, L., Sanz, T., Sahi, S., & Fiszman, S. M. (2014). Role of fibre morphology in some quality features of fibre-enriched biscuits. *International Journal of Food Properties*, *17*(1), 163–178. https://doi.org/10.1080/10942912.2011.619024

Li, Y., Wang, H., Wang, L., Qiu, J., Li, Z., & Wang, L. (2022). Milling of wheat bran: Influence on digestibility, hydrolysis and nutritional properties of bran protein during in vitro digestion. *Food Chemistry*, *404*, 134559. https://doi.org/10.1016/j.foodchem.2022.134559

Liu, L., Yang, T., Yang, J., Zhou, Q., Wang, X., Cai, J., Huang, M., Dai, T., Cao, W., & Jiang, D. (2022). Relationship of starch pasting properties and dough rheology, and the role of starch in determining quality of short biscuit. *Frontiers in Plant Science*, *13*, 829229. https://doi.org/10.3389/fpls.2022.829229

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Lu, G., & Gao, Q. (2011). Use of sweet potato in bread and flour fortification. In V. R. Preedy, R. R. Watson, & V. B. Patel (Eds.), *Flour and breads and their fortification in health and disease prevention* (pp. 407–416). Elsevier Inc. http://doi/10.1016/B978-0-12-380886-8.10037-6

Maia, L. C., Nano, R. M. W., Santos, W. P. C., Nascimento, P. V. B. S. D., Miranda, K. E. D. S., & Oliviera, F. S. D. (2020). Mineral profile and characterisation of cookies made from legume green grain flour. *Food Science and Technology*, *41*, 730–736. https://doi.org/10.1590/fst.22020

Mais, A., & Brennan, C. S. (2008). Characterisation of flour, starch and fibre obtained from sweet potato (kumara) tubers, and their utilisation in biscuit production. *International Journal of Food Science and Technology*, *3*(2), 373–379. https://doi.org/10.1111/j.1365-2621.2007.01652.x

Matthee, V., & Appledorf, H. (1978). Effect of cooking on vegetable fiber. *Journal of Food Science*, *43*, 1344–1345.

Menon, R., Padmaja, G. S., & Sajeev, M. (2015). Cooking behavior and starch digestibility of NUTRIOSE ® (resistant starch) enriched noodles from sweet potato flour and starch. *Food Chemistry*, *187*, 217–223. https://doi.org/10.1016/j.foodchem.2015.02.148

Mitiku, D. H., Abera, S., Bussa, N., & Abera, T. (2018). Physico-chemical characteristics and sensory evaluation of wheat bread partially substituted with sweet potato (*Ipomoea batatas* L.) flour. *British Food Journal*, *120*(8), 1764–1775. https://doi.org/10.1108/BFJ-01-2018-0015

Mitrović, J., Nikolić, N., Karabegović, I., Lazić, M., Nikolić, L., Savić, S., Pešić, M., Šimurina, O., & Stojanović-Krasić, M. (2021). The effect of thermal processing on the content and antioxidant capacity of free and bound phenolics of cookies enriched by nettle (*Urtica dioica* L.) seed flour and extract. *Food Science and Technology, Campinas*, *42*(1), 1–9. https://doi.org/10.1590/fst.62420

Nakov, G., Brandolini, A., Hidalgo, A., Ivanova, N., Jukic, M., Komlenic, D. K., & Lukinac, J. (2020). Influence of apple peel powder addition on the physico-chemical characteristics and nutritional quality of bread wheat cookies. *Food Science and Technology International*, *26*, 574–578. https://doi.org/10.1177/1082013220917282

Naqvi, S. N., Liaquat, M., Kazmi, A., Sammi, S., Ali, A., Luna-Arias, J. P., & Sherzad, I. U. (2024). Sesame-enriched delights: A comparative exploration of physicochemical and sensory attributes in fine and whole wheat flour cookies. *Food Science & Nutrition*, *12*(10), 7751–7765. https://doi.org/10.1002/fsn3.43430

Ohizua, E. R., Adeola, A. A., Idowu, M. A., Sobukola, O. P., Afolabi, T. A., Ishola, R. O., Ayansina, S., Oyekale, T. O., & Falomo, A. (2017). Nutrient composition, functional, and pasting properties of unripe cooking banana, pigeon pea, and sweet potato flour blends. *Food Science and Nutrition*, *5*, 750–762. https://doi.org/10.1002/fsn3.455

Okpala, L. C., & Ofoedu, P. I. (2018). Quality characteristics of cookies produced from sweet potato and heat flour blend fortified with brewer's spent grain flour. *Current Research in Nutrition and Food Science Journal*, *6*(1), 113–119. https://doi.org/10.12944/CRNFSJ.6.1.12

Olatunde, S. J., Ajayi, O. M., Ogunlakin, G. O., & Ajala, A. S. (2019). Nutritional and sensory properties of cake made from blends of pigeon pea, sweet potato and wheat flours. *Food Research*, *3*(5), 456–462. https://doi.org/10.26656/fr.2017.3(5).255

Olawoye, B., Gbadamosi, S. O., Otemuyiwa, I. O., & Akanbi, C. T. (2020). Gluten-free cookies with low glycemic index and glycemic load: Optimization of the process variables via response surface methodology and artificial neural network. *Heliyon*, *6*, e05117. https://doi.org/10.1016/j.heliyon.2020.e05117

Padmaja, G., Sheriff, J. T., & Sajeev, M. S. (2012). Food uses and nutritional benefits of sweet potato. *Fruit, Vegetable and Cereal Science and Biotechnology*, *6*(1), 115–123.

Ray, R. C., & Tomlins, K. I. (2010). Sweet potato: Post harvest aspects in food. In *Feed and industry*. Nova Science Publishers, Inc.

Reyes-Pérez, F., Salazar-García, M. G., Romero-Baranzini, A. L., Rosa Islas-Rubio, A., & Ramírez-Wong, B. (2013). Estimated glycemic index and dietary fiber content of cookies elaborated with extruded wheat bran. *Plant Foods for Human Nutrition*, *68*, 52–56. https://doi.org/10.1007/s11130-013-0338-0

Sanoussi, A. F., Adjatin, A., Dansi, A., Adebowale, A., Sanni, L. O., & Sanni, A. (2016). Mineral composition of ten Elites sweet potato (*Ipomoea batatas* [L.] Lam.) Landraces of Benin. *International Journal of Current Microbiology Applied Sciences*, *5*(1), 103–115. https://doi.org/10.20546/ijcmas.2016.501.009

Shaari, N., Shamsudin, R., Nor, M. Z. M., & Hashim, N. (2021). Quality attributes of Malaysia purple-fleshed sweet potato at different peel condition. *Agronomy*, *11*, 872. https://doi.org/10.3390/agronomy11050872

Singh, S., Riar, C. S., & Saxena, D. C. (2008). Effect of incorporating sweet potato flour to wheat flour on the quality characteristics of cookies. *African Journal of Food Science*, *2*, 065–072. http://www.academicjournals.org/ajfs

Singleton, V. L., Orthofer, R., & Lamuela-Raventos, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin–Ciocalteu reagent. *Methods in Enzymology*, *299*, 152–178. https://doi.org/10.1016/S0076-6879(99)99017-1

Sogabe, T., Kobayashi, R., Thanatuksorn, P., Suzuki, T., & Kawai, K. (2021). Physical and structural characteristics of starch-based and conventional cookies: Water sorption, mechanical glass transition, and texture properties of their crust and crumb. *Journal of Texture Studies*, *59*(3), 347–357. https://doi.org/10.1111/jtxs.12585

Tarancón, P., Sanz, T., Salvador, A., & Tárrega, A. (2014). Effect of fat on mechanical and acoustical properties of biscuits related to texture properties perceived by consumers. *Food and Bioprocess Technology*, *7*, 1725–1735. https://doi.org/10.1007/s11947-013-1155-z

Thongram, S., Tanwar, B., Chauhan, A., & Kumar, V. (2016). Physicochemical and organoleptic properties of cookies incorporated with legume flours. *Cogent Food and Agriculture*, *2*(1), 1172389, https://doi.org/10.1080/23311932.2016.1172389

Truong, V. D., Avula, R. Y., Pecota, K. V., & Yencho, G. C. (2018). Sweet potato production, processing, and nutritional quality. In M. Siddiq (Ed.), *Handbook of vegetables and vegetable processing* (pp. 811–838). John Wiley and Sons. https://doi.org/10.1002/9781119098935.ch35

Ubbor, S. C., Ekeh, J. I., Ejechi, M. E., Ndife, J., Agwo, O. E., & Iguh, B. N. (2021). Quality evaluation of shortbread biscuits produced from water yam-wheat flour blends. *FUDMA Journal of Agriculture and Agricultural Technology*, *7*(2), 53–66. https://doi.org/10.33003/jaat.2021.0702.048

van Chuyen, H., & Eun, J. B. (2013). Nutritional quality of foods: Sweet potato. In V. R. Preedy (Ed.), *Diet quality: An evidence-based approach* (pp. 247–256). Humana Press. https://doi.org/10.1007/978-1-4614-7339-8_19

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Yildirim, R. M., & Arici, M. (2019). Effect of the fermentation temperature on the degradation of phytic acid in whole-wheat sourdough bread. *LWT*, *112*, 108224. https://doi.org/10.1016/j.lwt.2019.05.122

Zhishen, J., Mengcheng, T., & Jianming, W. (1999). The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chemistry*, *64*, 555–559. https://doi.org/10.1016/S0308-8146(98)00102-2

How to cite this article: Belkacemi, L., Ozgolet, M., & Arici, M. (2025). Enhancing the nutritional and textural properties of gluten-free shortbread biscuits: The potential of white-fleshed sweet potato flour blended with corn starch. *Journal of Food Science*, *90*, e70123. https://doi.org/10.1111/1750-3841.70123

17503841, 2025, 3, Downloaded from https://ift.onlinelibrary.wiley.com/doi/10.1111/1750-3841.70123 by MUHAMMET ARICI - Turkey Cochrane Evidence Aid , Wiley Online Library on [22/03/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License