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Characterization of physicochemical, antioxidants and sensory properties of cookies enriched with shea (*Vitellaria paradoxa*) fruit pulp as a functional ingredient

Solomon Kofi Chikpah[1*], Joseph Kudadam Korese[2*] and Salamatu Osman[1]

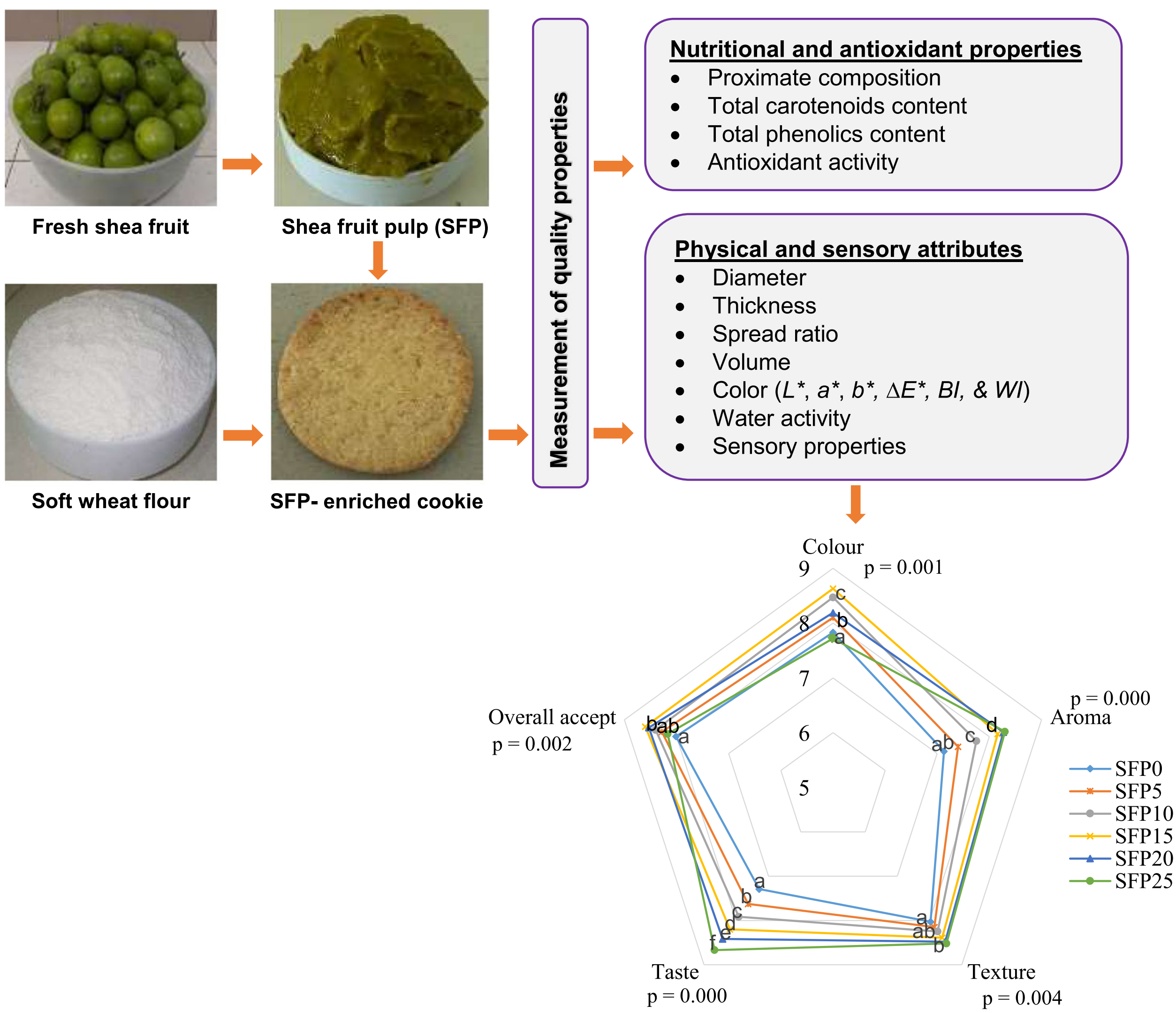
Abstract

The shea fruit pulp (SFP), a by-product generated during the processing of shea fruit, is a vital source of phytochemicals for the development of functional foods. This study determined the effect of partial substitution of wheat flour with SFP (0–25%) on the physicochemical, total carotenoids (TC), total phenolics content (TPC), antioxidant activity (AA), and sensory properties of cookies. The bromatological analysis showed that crude fiber, fat, and total ash contents of the SFP-enriched cookies increased by 155.3-565.8%, 1.7–6.8%, and 22.2-111.3%, respectively while moisture, crude protein, and available carbohydrate contents decreased by 10.0-44.9%, 3.1–17.5%, and 1.0-2.9%, respectively with increasing addition of SFP in the cookies. The SFP-enriched cookies had significantly higher TC (183.25-627.49 µg/100 g) and TPC (79.06–185.20 mg GAE/100 g) and AA (28.20-61.58%, inhibition) than the 100% wheat flour cookies, control (2.90 ± 0.14 µg/100 g for TC, 53.81 ± 5.70 mg GAE/100 g for TPC, and 15.79 ± 1.03% for AA). The incorporation of SFP in cookies decreases the thickness and whiteness index by 3.9–24.0% and 4.5–26.9%, respectively, but increases the spread ratio by 5.5–37.9% and the browning index by 10.3–87.4% as compared with the control cookies. Based on the sensory evaluation results, the 25% SFP-enriched cookie had the highest scores for taste, aroma, and texture whiles the 15% SFP-enriched cookie had the best rating for color and overall acceptability. It is conclusive that SFP could be utilized for the industrial production of cookies to enhance the nutritional, antioxidant, and sensory properties of the baked product. Nonetheless, enzymatic browning of the shea fruit pulp is a major limitation, and therefore, rapid processing of fruits and cold storage of the SFP is required to prevent the browning reactions of the SFP.

Keywords Shea fruit pulp, Cookies, Bromatological analysis, Phytochemicals, Antioxidant activity

*Correspondence:
Solomon Kofi Chikpah
schikpah@uds.edu.gh
Joseph Kudadam Korese
jkorese@uds.edu.gh
Full list of author information is available at the end of the article

Graphical Abstract



Background

There is a growing demand for safe and health-promoting foods possibly due to increased consumer awareness of the relationship between nutrition and health (De Ancos et al. 2015; Zlatanovic et al. 2019). Fruits and vegetable by-products such as pomace, peel, pulp, and seed portions generated during processing are good sources of phytochemicals and hence could be utilized in the manufacturing of functional foods (Babbar et al. 2015; Djeghim et al. 2021; Sahni & Shere 2020). Phytochemicals are crucial in the human diet due to their anti-oxidative, anti-cancer, hypoglycaemic, anti-microbial, cardioprotective, neuroprotective, anti-inflammatory, and immunomodulatory functions (Babbar et al. 2015; Kulczynski & Gramza-Michalowska 2019). Furthermore, phytochemicals like polyphenols could be utilized as bio-preservatives in processed foods (Babbar et al. 2015).

Cookies are popular and extensively consumed bakery products due to their ready-to-eat, convenience, palatability, affordable, and relatively long shelf life qualities (Korese et al. 2021; Zlatanovic et al. 2019). Nevertheless, cookies are largely prepared from refined wheat flour which is low in phytochemicals and high in digestible starch (Chikpah et al. 2020; Liu et al. 2020). Therefore, fortification of bakery products with phytochemicals riched plant-based ingredients is a major approach to enhance the nutritional value and health-promoting benefits of bakery products (Korese et al. 2021; Martinez &

Gomez 2019; Urganci & Isik 2021; Zlatanovic et al. 2019). Studies have shown that the phytochemicals content and antioxidant activity of cookies or biscuits improved when fortified with fruits and vegetable by-products such as mango peel powder (Ajila et al. 2008), pomegranate peel powder (Urganci & Isik 2021), pumpkin and carrot pomace (Turksoy & Özkaya 2011) and grape skin powder (Kuchtová et al. 2018). Furthermore, cookies prepared with peach palm fruit pulp flour and whole fruit (peel + pulp) flour had a total carotene content of 10.23 ± 0.41 mg/100 g and 18.1 ± 0.3 mg/100 g, respectively (Ribeiro et al. 2021). Moreover, the incorporation of apple pomace and grape skin powder in cookie formulation increased the aroma of the final baked cookies (Kuchtová et al. 2018; Sahni & Shere 2020). Nonetheless, the utilization of fruit pomace powder in bakery foods could give a bitter taste due to the high content of polyphenols (Ajila et al. 2008; Sahni & Shere 2020; Urganci & Isik 2021).

The shea fruit is an edible nutritious fruit produced from the shea tree (*Vitellaria paradoxa* C.F. Gaertn), an economic tree that grows well in the savannah regions of sub-Saharan Africa (Donkor et al. 2021; Honfo et al. 2014; Maranz et al. 2016). The shea fruit is ovoid and has a thin green skin (epicarp), soft sweet flesh (mesocarp) and an endocarp called the nut (Honfo et al. 2014; Korese & Chikpah 2022). The shea fruit pulp (epicarp + mesocarp) which constitutes a greater proportion of about 60–80% (w/w) of the whole fruit mass, is a by-product generated during the processing of the shea fruit for butter (Donkor et al. 2021; Korese & Chikpah 2022). The shea fruit pulp is a vital source of polyphenols (Korese & Chikpah 2022; Lamien-Meda et al. 2008), carotenoids, and vitamins (Honfo et al. 2014; Korese & Chikpah 2022), anthraquinones, alkaloids, saponins, glycosides, and tannins (Akoma et al. 2018), and dietary fiber (Donkor et al. 2021). Previous studies have shown that the shea fruit had total phenolics and flavonoids contents of 231.33 to 381.67 mg GAE/100 g and 20.70-30.95 mg QE/100 g of fruit respectively (Lamien-Meda et al. 2008), 191.1 mg/100 g d.b. of vitamin C and 7.0 mg/100 g d.b. of vitamin B (Honfo et al. 2014). Additionally, the shea fruit pulp contains essential macro and micro minerals (Akoma et al. 2018; Donkor et al. 2021; Korese & Chikpah 2022; Maranz et al. 2016) and high levels of sugar with a total sugar content of 74.60 ± 4.22 mg/g (Gyedu-Akoto et al. 2017). Sucrose, glucose, and fructose are major sugars present in the shea fruit pulp which give the pulp a sweet eating quality (Akoma et al. 2018; Korese & Chikpah 2022).

Despite the high nutritional and phytonutrient compositions, the shea fruit pulp remains underutilized in its growing regions, and in some cases, it ends up as waste material (Korese & Chikpah 2022). A thorough search of the literature has revealed that shea fruit pulp has not been utilized as an ingredient in bakery food production. Considering this research gap, this study is aimed to incorporate shea fruit pulp as a functional ingredient in the manufacturing of cookies and investigate the influence of shea fruit pulp on the physicochemical, antioxidant, and sensory properties of the fortified cookies. The feasibility of adding shea fruit pulp in cookie recipes will help expand its further application in the food industry as well as additional revenue for women who mostly process shea fruits for the nuts.

Materials and methods

Raw materials

The shea fruit pulp (SFP) utilized in this study was processed from freshly riped shea fruits harvested from wild-growing shea trees in Kpalbe (9° 6' 56" N, 0° 33' 1" W), in the North East Gonja District, Savanna Region, Ghana. The area falls under the Guinea Savannah zone with annual temperatures varying between 29 and 40 °C and annual rainfall ranging from 1112.7 to 1734 mm. A total of 480 fruits (13.87 kg) were collected from 15 shea trees. The fruits were harvested in the morning, placed in plastic baskets and transported to the laboratory where the fruits were kept at room temperature (23 ± 1 °C). The fruits were immediately processed within 10 h after harvest. The white soft wheat flour (Irani Brothers and Others Ltd, Ghana) was purchased from the central market of Tamale whereas the margarine made of 70% fat (Upfield Manufacturing Ltd, Tema, Ghana), sugar, refined iodized salt (ITC Network and Farms, Tema, Ghana), and baking powder (Weikfield Foods PVT. Ltd., Maharashtra, India) used for the preparation of the cookie were purchased from the Quality First supermarket in Tamale, Northern Region, Ghana.

Processing of shea fruit pulp

The fruits were washed manually with running tap water after which 235 non damaged fruits having uniform mass (28.73 ± 0.39 g) and color were selected for further processing. The pulp (epicarp and mesocarp) of the selected fruits was manually separated from the nut (endocarp) using a stainless steel knife. The SFP was blended with a Kenwood blender (BL400A, Kenwood Ltd, India) and sieved with a 500 µm particle size Amesh to obtain a fine SFP. Figure 1 shows the freshly riped shea fruits and pulp. About 4.68 kg of SFP was produced and stored in a refrigerator at -20 °C to prevent enzymatic browning reactions until all the baking experiments were completed within 3 days after the processing of fruits.

Fig. 1 Freshly riped shea fruits (left) and shea fruit pulp (right)

Cookies preparation

In this study, white soft wheat flour was partially substituted with SFP at the rate of 0, 5, 10, 15, 20, and 25% for the preparation of the cookies. The cookies were prepared as described by Korese et al. (2021) with some modifications. The recipe for the preparation of the cookies is indicated in Table 1. A total of 300 g of wheat flour or wheat + SFP blend was utilized for each batch of cookie preparation. The amount of margarine (50%), sugar (15%), salt (0.5%), and baking powder (1.5%) used were based on the quantity of wheat flour or SFP-wheat flour mixture. Before the start of the experiment, the SFP was removed from the refrigerator and defrosted under room conditions. The margarine and sugar were mixed in a mixing bowl with an electric hand-mixing machine (Kenwood HM330, Hampshire, UK) until a fluffy cream mixture was formed in about 3 min. The SFP was added to the cream and mixed for 1 min after which the wheat flour, salt, and baking powder were added and mixed for an additional minute. Optimum water determined in a pre-trial as indicated in Table 1 was added to the dough and mixing continued until a consistent dough was formed in about 1 to 2 min. The dough was kneaded into a 3-mm thickness using a manual dough sheeter with adjustable roller pins. The dough was cut into circular shapes with the aid of a 45 mm-diameter stainless steel cookie. The cookies were baked at 170 °C for 11 min in a conventional electric oven (Kaiser, EH 632, Berlin, Germany) that was pre-heated for 30 min. The baking conditions were selected based on pre-trials. After baking and cooling of cookies for about 1 h under room temperature of 23 ± 1 °C, all physical and sensory properties of the cookies were determined within 6 h after baking. However, cookie samples of each formulation were packed into a well-labeled high-density polyethylene bag and stored at -20 °C until chemical analyses were performed. Each baking experiment was replicated twice and a total of 40 cookies for each formulation were produced per batch of baking.

Determination of pH

The pH value of the SFP and wheat flour was determined using the procedure described by Karrar et al. (2020) with slight modification. In the present study, 5 g of the sample was homogenized in 40 ml of deionized distilled water and the pH value was measured using a digital pH meter (CRISON, Basic 20, Spain) at 23 °C. Three replicated measurements were taken for each sample.

Analysis of total soluble solids (°Brix)

The total soluble solids (TSS) content of the SFP and wheat flour was measured per the protocol described by

Table 1 Recipe for the cookies formulation

Ingredient	Cookies sample					
	SFP0	SFP5	SFP10	SFP15	SFP20	SFP25
Wheat flour (g)	300.0	285	270	255	240	225
Shea fruit pulp (g)	0.0	15	30.0	45	60	75
Margarine (g)	150.0	150	150	150	150	150
Sugar (g)	45.0	45.0	45.0	45.0	45.0	45.0
Salt (g)	1.5	1.5	1.5	1.5	1.5	1.5
Baking powder (g)	4.5	4.5	4.5	4.5	4.5	4.5
Water (ml)	50.0	30.0	20.0	10.0	0.0	0.0

Vizzotto et al. (2017). About 5 g of the sample was mixed with 25 ml of distilled water (30 °C) in a 50-ml centrifuge tube. The mixture was agitated for 15 min on a mechanical shaker and centrifuged in a Rotofix 32 A centrifuge (Andreas Hettich GmbH & Co. KG, Tuttlingen, Germany) at a speed of 4000 rpm for 30 min. The supernatant was collected and TSS (°Brix) was measured using a calibrated digital sucrose refractometer (MA871, Milwaukee Instruments Inc., Rocky Mount, USA) at 20 °C. Three replicated measurements were taken.

Sample preparation for bromatological analysis

Five cookies for each formulation were selected and milled into a fine powder using a Kenwood blender (BL400A, Kenwood Ltd, India). The powder was then packaged into high-density polyethylene bags wrapped with aluminum foil and stored in a refrigerator at 4 °C. All the chemical analyses were performed within 2–6 days after the cookies were produced.

Determination of proximate composition

The moisture, crude fat, crude protein, crude fiber, and total ash contents of the SFP, wheat flour, and cookies samples were determined following the standard procedures of the Association of Official Analytical Chemists (AOAC, 2006). Except for moisture the values of proximate components were expressed in grams per 100 g of the sample on a dry basis (d.b.). The available carbohydrate value was determined using the difference method as indicated in Eq. (1) (Achaglinkame et al. 2019). Also, the energy value (kcal) of the cookies samples was calculated using the Atwater calorie conversion factors method shown in Eq. (2) (FAO 2003). All analyses were replicated two times.

$$\text{Carbohydrate} = 100 - (\%\text{moisture} + \%\ \text{crude protein} + \%\text{fat} + \%\text{crude fibre} + \%\ \text{total ash}) \tag{1}$$

$$\text{Energy (kcal/100 g dm)} = \left[(9 \times \text{fat}(g)) + (4 \times \text{protein}(g)) + (4 \times (\text{carbohydrate}(g)))\right] \tag{2}$$

Total carotenoids analysis

The content of total carotenoids (TC) in the SFP, wheat flour, and cookies was analyzed following the procedure described by Md Saleh et al. (2019) with some modifications. The sample (5 g) was measured into a 100-ml volumetric flask wrapped with aluminum foil and 25 ml of the extraction solvent consisting of a mixture of hexane, acetone, and ethanol (2:1:1) was added. The mixture was then homogenized for 5 min followed by incubation in a refrigerator at 4 °C until the sample becomes white in about 1 h to ensure all carotenoids were completely extracted. The supernatant was filtered with a Whatman 4 filter paper and the filtrate was collected into a 100-ml volumetric flask. Distilled water (5 ml) was added to the supernatant for phase separation. The upper hexane layer containing the pigments was transferred into a 50-ml volumetric flask and the volume was made up of hexane. The absorbance was measured at a wavelength of 450 nm in a 10-mm glass cuvette with a UV-Vis double-beam spectrophotometer (JENWAY 6850, Germany). The concentration of TC was calculated using Eq. (3). The analysis was replicated twice.

$$\text{Total carotenoid } (\mu g.g^{-1}) = \frac{A_{450} \times V\ (ml) \times 10^4}{A_{1cm}^{1\%}\ \text{x sample weight (g)}} \tag{3}$$

Where A_{450} is absorbance; V is the total extract volume; and $A_{1cm}^{1\%} = 2500$ is the extinction coefficient of carotenoids in hexane.

Sample extraction for total phenolics and antioxidant activity analysis

Mostly, two extraction solvents (70% methanol and 70% acetone) are used for the extraction of phenolic compounds from plants and food materials (Lamien-Meda et al. 2008). In this experiment, SFP and wheat flour were extracted with 70% methanol whereas 70% acetone was found more suitable for the extraction of the cookies based on their extraction efficiency determined in a pre-trial. Briefly, 1 g of the sample was measured into a 100-ml volumetric flask previously wrapped with aluminum foil. About 10 ml of 70% methanol/pH 2 or 70% acetone/pH 2 was added depending on the sample. The sample and solvent were mixed thoroughly and incubated in the dark for 4 h at room temperature (23 ± 1 °C) with consistent shaking at every 1 h. The mixture was centrifuged at 4000 rpm for 15 min in a centrifuge (Rotofix 32 A, Andreas Hettich GmbH & Co. KG, Tuttlingen, Germany). The supernatant was collected and the residue was extracted two additional times following the above extraction procedure. All three supernatants collected were pooled and filtered through a Whatman No. 1 filter paper. The filtrate received was evaporated under a vacuum at 40 °C. The dried phenolics were dissolved in 10 ml of 70% methanol for SFP and wheat flour extract or 10 ml of 70% acetone for the cookie extract for further analysis.

Determination of total phenolics content

The total phenolics content (TPC) of the extracts was determined following the Folin–Ciocalteu method as described by Singleton et al. (1999) with some modifications based on (Li et al. 2015). About 0.5 ml of the diluted aqueous extract was measured into a 100-ml volumetric and mixed with 5 ml of Folin–Ciocalteu reagent. The mixture was then kept at room temperature (23 ± 1 °C) for 3 min after which 4 ml of sodium carbonate solution (75 g/l) was added and incubated for 2 h at room temperature (23 ± 1 °C). The absorbance was measured at a wavelength of 765 nm with a UV/Vis double-beam spectrophotometer (JENWAY 6850, Germany). The absorbance was read against water as the blank solution. The TPC was determined using a gallic acid standard calibration graph. The value of TPC was expressed as mg gallic acid equivalent (GAE) per 100 g of the sample on a d.b. Two replicated measurements were performed.

Determination of antioxidant activity

The antioxidant activity of the aqueous extract of each sample was measured by the 2,2-Diphenyl-2-picrylhydrazyl (DPPH) radical scavenging method as described in previous studies (Chikpah et al. 2022; Turkmen et al. 2005). About 0.5 ml of the aqueous extract or control (distilled water without sample) was measured into a 50-ml Falcon tube and 1.5 ml solution of 0.1 mM DPPH in methanol was added. The mixture was agitated for 5 min on a mechanical shaker and incubated in the dark for 1 h at room temperature (23 ± 1 °C). The absorbance was measured at a wavelength of 517 nm with a UV/Vis double-beam spectrophotometer (JENWAY 6850, Germany). The antioxidant activity in terms of percentage inhibition of DPPH free radicals using Eq. (4). The analysis was replicated two times.

$$\text{Antioxidant activity (\% inhibition)} = \left[1 - \left(\frac{A_s}{A_c}\right)\right] \text{x } 100 \quad (4)$$

Where A_c and A_s are the absorbances for the control and sample respectively.

Measurement of weight, dimensions, and volume of cookies

After baking and cooling for 1 h at room temperature, four cookies of each formulation were selected for the determination of physical quality attributes. The weight of the individual cookies selected was measured with a weighing scale (PBJ 620-3 M, KERN & SOHN GmbH, Germany), and the corresponding diameter (mm) and thickness (mm) of each cookie were measured with a digital vernier caliper (± 0.02 mm accuracy) following the procedures described by (Mancebo et al. 2015). The spread ratio was determined by dividing the diameter by thickness (Korese et al. 2021). The volume (cm^3) of each selected cookie was measured using the rapeseed displacement method 10–05.01 of the American Association of Cereal Chemists (AACC 2000) with a slight modification. In the present study, sesame seeds were used instead of rapeseed.

Determination of the color of raw materials and cookies

The CIELAB color coordinates (*L**, *a**, *b**) values of the SFP, wheat flour, and six cookies of each formulation were measured with a calibrated chroma meter (CR 400 Konica Minolta Inc., Marunouchi, Japan) as described in the previous studies (Chikpah et al. 2020; Korese et al. 2021). The L^* represents lightness and the values ranging from 0 (black) to 100 (white); a^* represents greenness ($a^* < 0$) or redness ($a^* > 0$) and b^* is yellowness ($b^* > 0$) or blueness ($b^* < 0$). The total color difference (ΔE^*), whiteness index (*WI*), and browning index (*BI*) are color parameters calculated from CIELAB color coordinates (L^*, a^* and b^*) using Eq. (5) (Chikpah et al. 2022), Eq. (6) (Lin et al. 2009) and Eq. (7) to (8) (Maciel & Teixeira 2022; Ureta et al. 2014), respectively.

$$\Delta E = \sqrt{\left(L_0^* - L^*\right)^2 + \left(a_o^* - a^*\right)^2 + \left(b_0^* - b^*\right)^2} \quad (5)$$

$$WI = 100 - \left[(100 - L^*)^2 + (a^*)^2 + (b^*)^2\right]^{1/2} \quad (6)$$

$$BI = \frac{[100(x - 0.31)]}{0.172} \quad (7)$$

$$x = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 3.012b^*)} \quad (8)$$

Where L^*, a^*, and b^* are the lightness, redness, and yellowness values. The L_o^*, a_o^*, and b_o^* in Eq. (5) represent the color values of the control cookies (100% wheat flour).

Determination of water activity of cookies

The water activity of the cookies after cooling was measured by a water activity meter (LabSwift-aw, Novasina AG, Switzerland) operated under room temperature (25

± 1 °C) (Korese et al. 2021). Two replicated measurements were performed on each sample.

Assessment of sensory properties of cookies

The likability of the color, aroma, taste, texture, and overall acceptability of the formulated cookies was judged by thirty untrained panelists consisting of 19 females and 11 males between the ages of 19 and 32 years. All the panelists are regular consumers of cookies. Also, the panelists were selected based on their willingness, availability, and previous sensory evaluation experience (Korese et al. 2021). The sensory evaluation was conducted in the food sensory laboratory of the Department of Family and Consumer Science of the University for Development Studies under room conditions (23 ± 1 °C), white light, and natural air circulation. Moreover, water was provided for rinsing the mouth between product assessments. The prepared cookies were placed in plastic containers with lids and assigned a three-digit code. A sensory evaluation questionnaire was presented to the assessors to rate the sensory attributes of the cookies using a 9-point hedonic scale that ranged from 1 (dislike extremely) to 9 (like extremely) (Korese et al. 2021; Rao et al. 2016).

Statistical analysis

The data obtained were analyzed in a one-way analysis of variance (ANOVA) and Tukey's pairwise comparison test was carried out at a 5% significance level to separate means. Furthermore, Pearson correlation and principal component analysis were performed to identify the correlation between the quality attributes and differentiate between the cookies samples. All statistical analyses were performed with SPSS software (IBM SPSS Statistics, version 25).

Results and discussion

Physicochemical properties of SFP and wheat flour

The physical and chemical properties of flour and other ingredients utilized for bakery products manufacturing have an important influence on the processing and quality of the final baked products. Table 2 shows the physicochemical properties of the SFP and wheat flour utilized for the preparation of the cookies. It was obvious that the SFP had significantly higher moisture, total soluble solids, crude fiber, crude fat, and total ash content but had lower pH, crude protein, and available carbohydrate values than the wheat flour. As expected, the SFP had a higher TC value (299.86 ± 13.52 mg/100 g) and TPC (374.91 ± 15.7 mg GAE/100 g) as compared with the value of 0.57 ± 0.02 mg/100 g for TC and 63.80 ± 2.90 mg GAE/100 g for TPC of the wheat flour (Table 2). As expected, the wheat flour has a higher L^* value and lower a^* and b^* values than the SFP. This means the SFP is more greenish and yellowish than the wheat flour. The higher a^* and b^* values observed in the SFP correlates positively with high total carotenoids and total phenolics contents.

Table 2 Physicochemical properties of shea fruit pulp and wheat flour utilized for the preparation of cookies

Parameter	Shea fruit pulp	Wheat flour
Moisture (% w.b)	67.04 ± 0.29^b	12.77 ± 0.15^a
pH	5.18 ± 0.01^a	6.28 ± 0.01^b
Total soluble solids (°Brix)	4.10 ± 0.01^b	0.73 ± 0.00^a
Crude protein (% w.b)	2.78 ± 0.10^a	12.92 ± 0.13^b
Crude Fat (% w.b)	2.96 ± 0.01^b	1.03 ±0.01^a
Crude fiber (% w.b)	8.74 ± 0.06^b	0.49 ±0.02^a
Total ash (% w.b)	2.13 ± 0.03^b	1.60 ± 0.01^a
Available carbohydrate (% w.b)	16.35 ± 0.14^a	71.19 ± 0.37^b
Total carotenoids (mg/100 g)	299.86 ± 13.52^b	0.57 ± 0.02^a
Total phenolics (mg GAE/100 g)	374.91 ± 15.73^b	63.80 ± 2.90^a
L^*	47.06 ± 0.19^a	91.87 ± 0.53^b
a^*	-2.17 ± 0.04^b	-0.46 ± 0.05^a
b^*	31.58 ± 0.12^b	11.69 ± 0.08^a

Values represent means ± standard deviation. L*, a* and b* represent lightness, greenness and yellowness respectively

Proximate composition of the cookies

Table 3 indicates the proximate composition and energy value of the SFP-enriched and control cookies. The addition of SFP in the cookies significantly ($p < 0.05$) influenced the proximate composition of cookies. The proximate composition of the formulated cookies varied from 3.25 to 5.90% for moisture, 25.37 to 27.08 g/100 g d.b. for crude fat, 8.20 to 9.94 g/100 g d.b. for crude protein, 0.38 to 2.53 g/100 g d.b. for crude fiber, 1.94 to 4.10 g/100 g d.b. for total ash and 54.83 to 56.47 g/100 g d.b. for available carbohydrate. A comparison between the nutritional composition of the control and SFP-enriched cookies in Table 3, has revealed a significant increase of about 155.3–565.8%, 1.7–6.8%, and 22.2–111.3% in the crude fiber, crude fat, and total ash contents of SFP-enriched cookies respectively with increasing substitution of wheat flour with SFP. Nonetheless, the moisture content, crude protein, and available carbohydrate contents of the SFP-enriched cookies decreased by 10.0-44.9%, 3.1–17.5%, and 1.0-2.9%, respectively as compared with the control cookies. The variation in the proximate compositions of the cookies could be attributed to differences in the proximate composition of SFP and WF as shown in Table 2. Similarly, Urganci & Isik (2021) reported a decrease in protein content and an

Table 3 Proximate composition of the cookies as affected by the incorporation of shea fruit pulp

Nutritional component	Cookies sample (%WF: %SFP)					
	SFP0 (100:00)	SFP5 (95:5)	SFP10 (90:10)	SFP15 (85:15)	SFP20 (80:20)	SFP25 (75:25)
Moisture (%)	5.90 ± 0.08^{d}	5.31 ± 0.06^{c}	5.08 ± 0.19^{c}	4.70 ± 0.14^{c}	3.98 ± 0.07^{b}	3.25 ± 0.05^{a}
Crude fat (g)	25.37 ± 0.07^{a}	25.81 ± 0.03^{ab}	26.11 ± 0.08^{bc}	26.42 ± 0.05^{bcd}	26.76 ± 0.06^{cd}	27.09 ± 0.04^{d}
Crude protein (g)	9.94 ± 0.12^{d}	9.63 ± 0.12^{d}	9.22 ± 0.05^{c}	8.78 ± 0.23^{b}	8.51 ± 0.10^{ab}	8.20 ± 0.06^{a}
Total ash (g)	1.94 ± 0.03^{a}	2.37 ± 0.04^{b}	2.77 ± 0.06^{c}	3.19 ± 0.07^{d}	3.63 ± 0.03^{e}	4.10 ± 0.03^{f}
Crude fibre (g)	0.38 ± 0.02^{a}	0.97 ± 0.01^{b}	1.32 ± 0.01^{c}	1.70 ± 0.03^{d}	2.11 ± 0.01^{e}	2.53 ± 0.01^{f}
Available carbo.(g)	56.47 ± 0.18^{b}	55.91 ± 0.13^{ab}	55.50 ± 0.20^{ab}	55.21 ± 0.15^{ab}	55.01 ± 0.12^{ab}	54.83 ± 0.16^{a}
Energy value (kcal)	493.97 ± 0.84^{a}	494.45 ± 0.49^{a}	493.87 ± 0.92^{a}	493.74 ± 0.53^{a}	494.92 ± 0.76^{ab}	495.89 ± 0.61^{b}

The values are average ±standard deviation ($n = 2$) and expressed on a dry basis except for moisture content. carbo. represent carbohydrate. Values within a row having no common superscript letter are significantly different ($p < 0.05$)

increase in fat, total ash, and total dietary fiber contents of biscuits supplemented with pomegranate peel powder. Furthermore, the addition of mango peel powder into the formulation of biscuits increased the total dietary fiber content of the final products (Ajila et al. 2008). The energy value of the cookies varied between 493.74 and 495.89 kcal/100 g d.b. (Table 3). The energy values of the control cookies and SFP-enriched cookies were statistically similar ($p > 0.05$), except for sample SFP25 (25% SFP-based product) which has a slightly higher energy value as compared with the control cookies (Table 3). This phenomenon could be the result of the higher fat content observed in the 25% SFP-enriched cookies.

Antioxidant properties of the cookies

The values of TC, TPC, and antioxidant activity in terms of DPPH free radical scavenging activity of the cookies are presented in Table 4. The TC values of the SFP-enriched cookies ranged between 83.25 and 627.49 µg/100 g d.b., about 63.2 to 216.4 folds higher than the value measured in the control cookies (2.90 ± 0.14 µg/100 g d.b.). Also, the TPC increased greatly from 53.81 ± 5.70 mg GAE/100 g d.b. in the control (SFP0) to 79.06–185.20 mg GAE/100 g d.b. in the SFP-enriched cookies. The TPC increased 46.9-244.2% in the SFP-enriched cookies with increasing SFP addition from 5 to 25%. The increase in TC and TPC content of the SFP-enriched cookies can be attributed to the high levels of TC and TPC observed in the raw SFP (Table 2). The trend of results observed in this study was in agreement with that of Urganci & Isik (2021) who reported an increase in the TPC of biscuits fortified with pomegranate seed powder. Also, an increase in the TPC of pearl-millet biscuits fortified with orange peel flour was reported (Obafaye & Omoba 2018). Similar to the observations reported on biscuits enhanced with mango peels and kernel powder (Aslam et al. 2014) and pomegranate seed powder (Urganci & Isik 2021), the antioxidant activity of the formulated cookies increased from 15.79% in the control to 61.58% in the 25% SFP-enriched cookies. This observation can be attributed to the increase in TC and TPC values of the cookies with increasing SFP (Chikpah et al. 2022; Korese et al. 2021).

Physical properties of cookies

Table 5 shows the variations in the weight, diameter, thickness, volume, and spread ratio values of the cookies as affected by the rate of SFP incorporation in the cookies formula. The SFP-based cookies had significantly ($p < 0.05$) lower weight (8.42 to 9.65 g), thickness (4.90 to 6.20 mm), and volume (9.05 to 12.10 cm^3) as compared with the values of the control cookie (9.95 ± 0.03 g, 6.45 ± 0.07 mm, and 12.85 ± 0.21 cm^3, respectively).

Table 4 Some selected antioxidant properties of the control and SFP-enriched cookies

Cookies sample (%WF:%SFP)	Total carotenoids (µg/100 g d.b.)	Total phenolics content (mg GAE/100 g d.b.)	Antioxidant activity (% DPPH inhibition)
SFP0 (100:0)	2.90 ± 0.14^{a}	53.81 ± 5.70^{a}	15.79 ± 1.03^{a}
SFP5 (95:5)	183.25 ± 10^{b}	79.06 ± 8.12^{b}	28.20 ± 3.19^{b}
SFP10 (90:10)	295.91 ± 22^{c}	102.14 ± 4.56^{c}	37.62 ± 1.72^{c}
SFP15 (85:15)	408.13 ± 34^{d}	123.72 ± 9.58^{d}	42.86 ± 3.93^{d}
SFP20 (80:20)	539.72 ± 15^{e}	151.68 ± 7.02^{d}	53.71 ± 3.05^{e}
SFP25(75:25)	627.49 ± 19^{f}	185.20 ± 6.93^{e}	61.58 ± 1.80^{f}

Values represent mean±standard deviation ($n = 2$). Values with different superscript letters are significantly different ($p < 0.05$)

Table 5 Physical properties of the control and SFP-enriched cookies

Cookies sample	Weight (g)	Diameter (mm)	Thickness (mm)	Volume (cm^3)	Spread ratio
SFP0	9.95 ± 0.03^e	45.91 ± 0.15^a	6.45 ± 0.07^d	12.85 ± 0.21^f	7.12 ± 0.14^a
SFP5	9.65 ± 0.04^d	46.52 ± 0.09^b	6.20 ± 0.05^d	12.10 ± 0.14^e	7.51 ± 0.18^a
SFP10	9.51 ± 0.06^d	47.21 ± 0.13^c	5.83 ± 0.02^c	11.34 ± 0.07^d	8.10 ± 0.10^b
SFP15	9.14 ± 0.08^c	47.66 ± 0.08^d	5.40 ± 0.04^b	10.65 ± 0.21^c	8.83 ± 0.07^c
SFP20	8.79 ± 0.04^b	47.99 ± 0.11^e	5.12 ± 0.08^{ab}	9.80 ± 0.14^b	9.37 ± 0.09^d
SFP25	8.42 ± 0.04^a	48.15 ± 0.07^e	4.90 ± 0.06^a	9.05 ± 0.09^a	9.82 ± 0.12^e

Value represent mean±standard deviation ($n = 4$). SFP0 is the control cookies, SFP5, SFP10, SFP15, SFP20, and SFP25 are cookies formulated with 5, 10, 15, 20, and 25% SFP respectively. Values in a column with different superscript letters are statistically different ($p < 0.05$)

The addition of SFP in the cookies formula resulted in a reduction in the thickness and volume of cookies by 3.9–24.3% and 5.8–29.6%, respectively. Similar trends were reported in cookies supplemented with red grape skin powder (Kuchtová et al. 2018), and muffins enriched with red and white grape pomace (Walker et al. 2014). The reduction in the thickness and volume of the SFP-enriched cookies can be attributed to the dilution of gluten and the increase in fiber content of the wheat-SFP composite dough (Korese et al. 2021; Kuchtová et al. 2018). Mostly, a decrease in gluten and an increase in the fiber content of flour can decrease gluten network development, viscosity, and CO_2 retention capacity and subsequently decrease the thickness and volume of baked foods (Chikpah et al. 2021; Korese et al. 2021; Kuchtová et al. 2018; Walker et al. 2014). However, the diameter and spread ratio of the cookies increase from 45.91 to 48.15 mm and 7.12 to 9.82, respectively with increasing incorporation of SFP. Mostly, the spread rate of cookies is dependent on the viscosity of the dough and hence, a decrease in gluten and an increase in the dissolved sugar content of dough as in the case of wheat flour substitution with SFP addition can reduce the initial viscosity of dough and thus increase the spread of cookies during baking (Kaldy et al. 1993; Miller et al. 1997). Similarly, an increase in the diameter and spread ratio of cookies was reported for biscuits fortified with grape seed powder (Aksoylu et al. 2015) and wheat-oranged fleshed sweet potato composite cookies (Korese et al. 2021). On the contrary, Kuchtová et al. (2018) observed that partial substitution of wheat flour with red grape skin powder reduced the diameter and spread ratio of cookies for cookies enriched. Additionally, the inclusion of pumpkin and carrot pomace powder in cookies (Turksoy & Özkaya 2011) and mango peel powder in biscuits (Aslam et al. 2014) decreased the spread ratio of the baked products. The contrasting results observed in the different studies can be attributed to differences in the chemical compositions of raw materials and formulations of cookies.

Water activity of the cookies

Water activity (a_w) is an important quality parameter of baked products due to its influence on the product's textural, shelf life, and sensory properties after baking and during storage (Cauvain & Young 2009; Korese et al. 2021; Malavi et al. 2022). The a_w values of the cookies as influenced by the incorporation of SFP are presented in Fig. 2. The values of a_w of the cookies differed between 0.185 and 0.348. Similar to the previous finding by Korese et al. (2021) on wheat-orange fleshed sweet potato composite flour cookies, the a_w values of the cookies decreased greatly with the increasing addition of SFP in the cookie formula. For the cookies produced the a_w values of all the cookies produced were below the threshold of 0.6 recommended for cookies for safe storage (Cauvain & Young 2006).

Visual appearance and color of cookies

Physical appearance and color are crucial attributes used to judge the quality of baked foods and thus influence consumer acceptability (Hager et al. 2012; Korese et al. 2021; Sahni & Shere 2020). Generally, the physical appearance and color of baked food are largely dependent on the color of the raw materials and chemical reactions like Maillard reaction and caramelization (Ameur et al. 2007; Barros et al. 2018; Chikpah et al. 2021; Korese et al. 2021; Manley 2011). The visual appearance of the control and SFP-enriched cookies is indicated in Fig. 3. It was obvious that the incorporation of SFP in cookies influences their visual appearance. The cookie's surface lightness decreased while the brown coloration increased with an increased percentage of SFP in the cookies.

Table 6 shows the L^*, a^*, b^*, WI, BI, and ΔE^* values of the control and SFP-based cookies as affected by the addition of SFP in the cookies formulation. The values of L^* and WI of cookies decreased from 74.23 to 59.45 for L^* and 59.13 to 43.20 for WI whereas a^*, b^*, BI, and

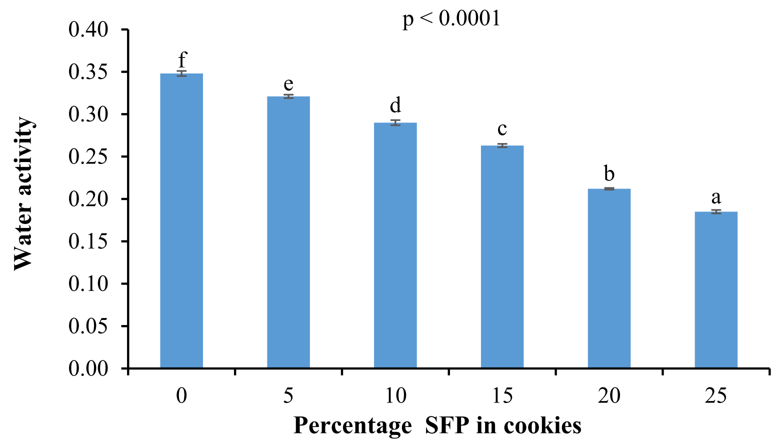


Fig. 2 Water activity of cookies as influenced by the degree of SFP incorporation. Values are averages of two replicated measurements. Error bars represent standard deviations ($n = 2$). Values with different lowercase letters are significantly different ($p < 0.05$)

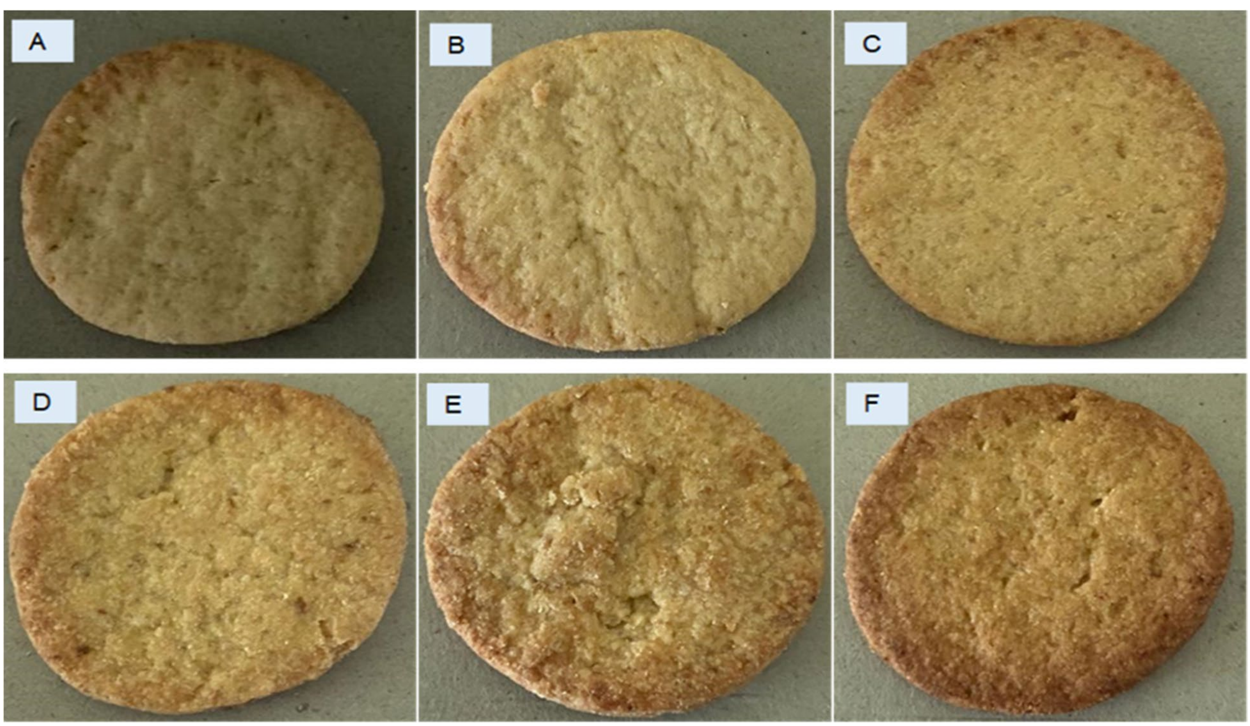


Fig. 3 Photos showing the visual appearance of control cookies. Sample **A**, **B**, **C**, **D**, **E**, and **F** represent the control, 5, 10, 15, 20, and 25% shea fruit pulp-based cookies respectively.

ΔE^* increased from 1.14 to 6.78, 31.70 to 35.83, 54.41 to 101.94 and 3.09 to 19.11, respectively with increasing addition of SFP in the formulated cookies. Similarly, Turksoy & Özkaya (2011) reported a reduction in lightness and an increase in redness and yellowness of cookies supplemented with pumpkin pomace powder. Moreover, the incorporation of pomegranate peel powder (Urganci & Isik 2021) and blueberry grape seed powder (Aksoylu et al. 2015) in biscuits preparation decreased the surface lightness and yellowness values but increased the redness value of the baked products. Additionally, the increasing substitution of wheat flour with pomegranate peel powder increased the ΔE^* value of biscuits (Urganci & Isik 2021), similar to the results obtained in this study (Table 6). The increase in yellowness of the cookies with the addition of SFP can

Table 6 Color parameters of cookies as influenced by the percentage of SFP incorporation in the cookies formulation

Color paramter	Cookies sample (%WF: %SFP)					
	SFP0 (100:0)	SFP5 (95:5)	SFP10 (90:10)	SFP15 (85:15)	SFP20 (80:20)	SFP25 (75:25)
L*	74.23 ± 0.74^{e}	71.34 ± 0.62^{d}	64.53 ± 0.98^{c}	63.18 ± 0.23^{bc}	62.03 ± 0.35^{b}	59.45 ± 0.66^{a}
a*	1.14 ± 0.08^{a}	1.40 ± 0.26^{a}	2.85 ± 0.22^{b}	3.46 ± 0.49^{b}	4.96 ± 0.55^{c}	6.78 ± 0.16^{d}
b*	31.70 ± 0.36^{a}	32.75 ± 0.10^{b}	33.82 ± 0.35^{c}	34.77 ± 0.19^{d}	35.17 ± 0.41^{d}	35.83 ± 0.22^{e}
BI	54.41 ± 1.09^{a}	60.05 ± 1.07^{b}	73.58 ± 1.38^{c}	79.45 ± 1.48^{d}	84.66 ± 1.61^{e}	101.94 ± 1.55^{f}
WI	59.13 ± 0.46^{e}	56.46 ± 0.45^{d}	50.90 ± 0.87^{c}	49.23 ± 0.56^{bc}	48.01 ± 0.23^{b}	43.20 ± 0.45^{a}
ΔE*	-	3.09 ± 0.07^{a}	10.08 ± 0.14^{b}	11.71 ± 0.09^{bc}	13.27 ± 0.12^{c}	19.11 ± 0.18^{d}

Values are presented as mean ± standard deviation ($n = 6$). WF and SFP represent wheat flour and shea fruit pulp respectively. L* (lightness), a*(redness), b* (yellowness), BI (browning index), WI (whiteness index) and ΔE* (total color difference)

Values in a row with different superscript letters are statistically different ($p < 0.05$)

be related to the carotenoids in the SFP, similar to the observation made in wheat-orange fleshed sweet potato composite composite cookies (Korese et al. 2021). The declined in L^* and WI and increased in BI and ΔE values of the cookies with increasing addition of SFP could be attributed to Millard and caramelization reactions expedited by high sugars and polyphenols contents of SFP causing the creation of brown compounds and surface darkening of the cookies (Ameur et al. 2007; de Barros et al. 2020; Korese et al. 2021; Manley 2011; Sahni & Shere 2020).

Sensory properties of the cookies

Mostly, the appearance, color, flavor, taste, and texture are vital organoleptic properties that greatly influence consumer acceptability of cookies (Korese et al. 2021; Rao et al. 2016; Sahni & Shere 2020; Urganci & Isik 2021). The rate of SFP incorporation in the cookies significantly ($p < 0.05$) affected the likeness scores for appearance, color, aroma, texture, taste, and overall acceptability of the cookies (Fig. 4). The average color likeness scores of the cookies varied between 7.72 (like very much) and 8.63 (like extremely). The color likeness score increased with the increasing addition of SFP but a slight decline in color likeness was observed as the SFP incorporation in the cookies formulation exceeded 15%. The increase in yellowness and intensified browning and surface darkening observed in cookies with higher levels of SFP (20–25%) could be the cause of the reduction in color rating score (Korese et al. 2021; Manley 2011). Similar to the

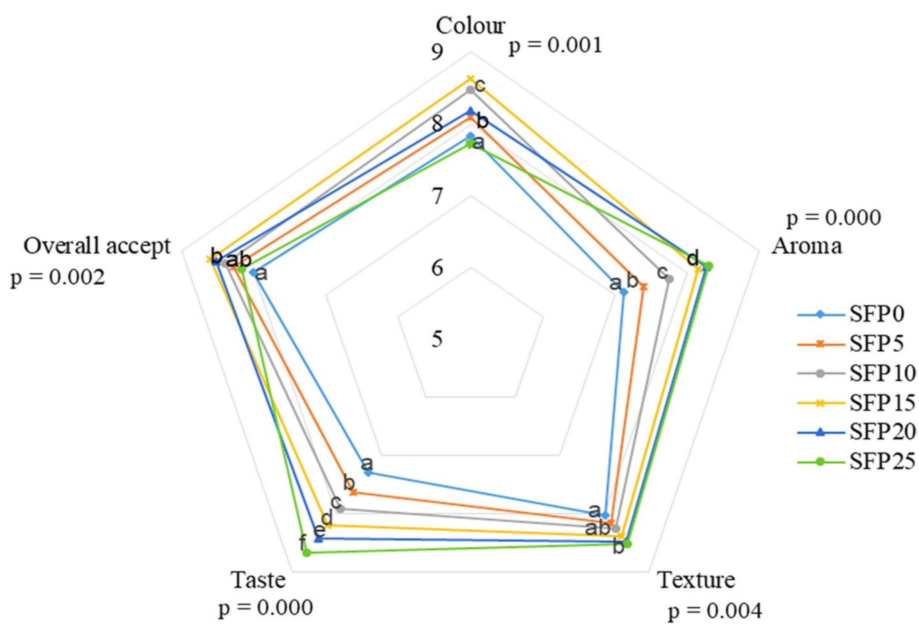


Fig. 4 Sensory properties of the control and SFP-enriched cookies. Sample SFP0, SFP5, SFP10, SFP15, SFP20, and SFP25 represent the 0, 5, 10, 15,20, and 25% SFP-enriched cookies. Values with different letters are statistically different ($p < 0.05$)

observations made on cookies fortified with apple pomace powder (Sahni & Shere 2020) and grape skin powder (Kuchtová et al. 2018), the aroma likeness score increased from 7.13 (like moderately) to 8.30 (like very much) as the addition of SFP. This phenomenon could be attributed to the fruity aroma of the shea fruit and also the increased fat content in the SFP-based cookies because fat helps to entrap and maintain flavor and enhance the mouth feel of the cookie (Pareyt & Delcour 2008).

Like the aroma, increasing the addition of SFP in the cookies resulted in an increase in the taste likeness score from 7.29 for the control to 8.67 for the 25% SFP-based cookies. This observation could be due to sugars present in shea fruit pulp. Nonetheless, the taste of biscuits decreased when wheat flour was replaced with 25% of mango peel powder (Ajila et al. 2008) and 12–18% of pomegranate peel powder (Urganci & Isik 2021). These contrasting results could be due to variations in polyphenols and sugar contents of the fruit-by products. The high polyphenols content in fruit pomace powder gives a bitter taste to products (Sahni & Shere 2020). However, the presence of high sugar in the SFP could neutralize or mask the bitter taste effect of polyphenols which may be the case in the present study. For cookie crispness the scores varied from 8.03 for the control to 8.52 for the 25% SFP-enriched based cookies. This was expected because SFP has a considerable amount of fat that can influence the dough properties and structural and textural attributes of the final baked cookies. According to Pareyt & Delcour (2008), fat can disrupt gluten and starch interactions in dough and reduce the elasticity of the dough which increases the tenderness of the final baked cookies.

As shown in Fig. 4, all the cookies formulated in this study had an overall acceptability score between 8.01 and 8.60 (like very much to like extremely) per the 9-hedonic scale. Predominantly, the SFP-enriched cookies had slightly higher acceptability than the control cookie. The cookie formulated with 15–20% SFP had the highest overall acceptability (like extremely). However, previous studies observed that the incorporation of 5% of grape skin powder or grape seed powder in cookies (Kuchtová et al. 2018), 10% mango peel powder in biscuits (Ajila et al. 2008), and 6% of pomegranate peel powder in biscuits (Urganci & Isik 2021) and had the best overall acceptability.

The influence of the product and assessor on the sensory performance of the cookies products was determined by the analysis of variance (ANOVA) and the results are presented in Table 7. The variation in the product formulation had a significant (p < 0.05) effect on all the sensory attributes. The assessor effect on color, texture, and overall acceptability was insignificant (p > 0.05). Nonetheless, significant variations were observed among the scores of assessors for the aroma and taste of the same product. This observation may be attributed to physiological differences that may exist between assessors (Li et al. 2020). Similar to the findings by Li et al. (2020), for all the sensory attributes, the product F-values were much higher than their assessor F-values (Table 7). This suggests that the product has a superseding effect on the sensory attributes than the assessor.

Table 7 Product and assessor effects on the sensory attributes of the cookies

Sensory parameter	Product effect (*df* =5)		Assessor effect (*df* = 29)	
	F-value	P-value	F-value	*P*-value
Color	18.486	0.001	0.823	0.724
Aroma	6.068	0.000	1.548	0.043
Texture	7.333	0.004	1.363	0.119
Taste	6.732	0.000	3.823	0.015
Overall acceptability	23.772	0.002	0.503	0.984

df is the degree of freedom

Principal component analysis (PCA)

In this study, PCA was carried out to determine the correlation between the quality characteristics of the cookies, the predominant quality attributes in the cookies products, and finally to identify whether the cookies samples were different or similar in terms of their quality characteristics (Azam et al. 2018; Chikpah et al. 2021; Djeghim et al. 2021; Korese et al. 2021; Li et al. 2020). Figure 5a illustrates the correlation loading plot which indicates the relationships between the quality characteristics of the cookies. From the PCA results, two principal components were extracted where about 88.70% and 9.85% of the total variance in the original data were explained by the first component (PC1) and the second component (PC2) respectively. These two principal components accounted for 98.55% of the total variance and, therefore, statistically adequate to distinguish between the samples (Korese et al. 2021; Li et al. 2020). The score plots (Fig. 5b) revealed great differences in the various cookie samples as indicated by the even distribution of the samples in the four quadrates. It was observed from the correlation loading plot in Fig. 5a, that quality attributes like fat, diameter, redness, yellowness, BI, antioxidants, aroma, taste, and texture described the positive axis of PC1. These attributes were dominated in cookie samples SFP20 and SFP25 (20% and 25% SFP-based cookies, respectively). Cookies attributes like moisture, crude protein (CP), carbohydrate, thickness, volume, lightness, and WI which predominate in the control cookie (SFP0) characterized the negative axis of PC1. Besides, sensory

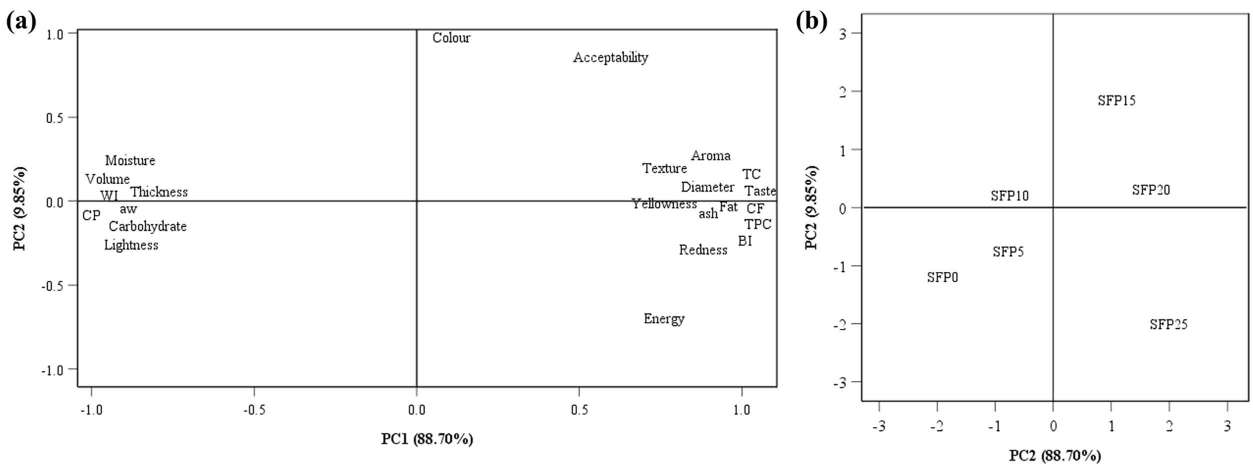


Fig. 5 Principal component analysis of quality attributes of cookies samples. (**a**) Correlation loading plot and (**b**) score plot generated from the PCA

attributes such as color and overall acceptability were key attributes in sample SFP15 located on the positive axis of PC 2.

The result of the correlation analysis has shown various degrees of correlation between the physicochemical and sensory characteristics of the cookies as indicated in Table 8. The moisture content showed a strong inverse correlation with BI, aroma, texture, and taste (r = -0.948 to -0.975, $p < 0.01$). Similarly, Korese et al. (2021) reported a negative correlation between moisture content and the crispness of wheat-OFSP composite cookies. However, a strong positive relationship was observed between fat and sensory attributes like aroma, texture, taste (r = 0.990 to 0.998, $p < 0.01$), and overall acceptability (r = 0.718, $p < 0.05$). This suggests that an increase in the fat content of the cookies will increase the aroma, texture, and taste likeness of the cookies since fat helps to maintain flavor and improves the crispness of cookies (Pareyt & Delcour 2008). Moreover, BI had a strong linear correlation with the aroma and taste of the cookies (r = 0.988, $p < 0.01$). This was expected because the products of Millard reactions help to enhance the flavor and taste of baked foods.

Conclusion

High nutritious and consumer-acceptable SFP-enriched cookies were developed. The incorporation of SFP in the cookies greatly increased the contents of bioactive compounds such as dietary fiber, total carotenoids, and total phenolics contents, and improves the antioxidant activity

Table 8 Pearson correlations between the physicochemical and sensory attributes of the SFP-enriched cookies

Parameter	MC	Fat	CP	Ash	CF	TC	SR	WI	BI	Color	Aroma	Texture	Taste	Accept.
MC		-0.984**	0.970**	-0.988**	-0.983**	-0.977**	-0.974**	0.954**	-0.975**	0.179	-0.948**	-0.955**	-0.973**	-0.281
Fat			-0.995**	0.998**	1.000***	0.998**	0.992**	-0.981**	0.980**	-0.001	0.998**	0.990**	0.995**	0.718*
CP				-0.995**	-0.993**	-0.998**	-0.998**	0.982**	-0.979**	-0.038	-0.980**	-0.995**	-0.997**	-0.465
Ash					0.997**	0.997**	0.996**	-0.980**	0.986**	-0.042	0.959**	0.987**	0.990**	0.398
CF						0.996**	0.990**	-0.980**	0.978**	0.003	0.964**	0.989**	0.998**	0.441
TC							0.997**	-0.980**	0.999***	0.018	0.974**	0.994**	0.998**	0.456
SR								-0.973**	0.976**	-0.005	0.973**	0.992**	0.993**	0.435
WI									-0.992**	-0.051	-0.954**	-0.967**	-0.985**	-0.419
BI										-0.072	0.988**	0.956**	0.979**	0.315
Color											0.223	0.098	0.049	0.997**
Aroma												0.990**	0.977**	0.725*
Texture													0.994**	0.596
Taste														0.575
Accept.														

MC, CP, CF, TC, SR, WI, BI, and Accept. represent moisture content, crude protein, crude fiber, total carotenoids, spread ratio, whiteness index, browning index, and overall acceptability respectively. Values with *, **, *** superscripts show significant correlation at 0.05, 0.01, and 0.001 significant levels respectively in terms of DPPH free radical scavenging capacity. Furthermore, the cookie's diameter, spread ratio, *a**, *b**, and *BI* increased while the volume, *L**, and *WI* decreased with increasing incorporation of SFP in the cookies. The SFP has improved the sensory attributes and overall consumer acceptability of the cookies. The 15% SFP-based cookies had the highest overall acceptability. However, processors could use up to 25% SFP in cookies without adverse effects on the acceptability of the cookies. The enzymatic browning of the shea fruit pulp is a major limitation, and therefore, rapid processing of fruits and cold storage of the SFP is required to prevent the browning reactions of the SFP. Future research should focus on pretreatments of SFP to deactivate enzymatic browning reactions as well as the utilization of SFP as a fat and sugar replacer for the development of low-fat and sugar cookies.

Abbreviations

*a**	Red/green color coordinate
a_w	Water activity
*b**	Yellow/blue color coordinate
BI	Browning index
d.b.	Dry basis
DPPH	2,2-Diphenyl-2-picrylhydrazly
ΔE*	Total color difference
GAE	Gallic acid equivalent
*L**	Lightness
PCA	Principal component analysis
SFP	Shea fruit pulp
TC	Total carotenoids
TPC	Total phenolics content
TSS	Total soluble solids
w.b	Wet basis
WF	Wheat flour
WI	Whiteness index

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43014-023-00152-1.

Additional file 1.

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Authors' contributions

Solomon Kofi Chikpah: Conceptualization, Methodology, Investigation, Formal analysis, Resources, Validation, Writing-original draft. Joseph Kudadam Korese: Conceptualization, Resources, Funding acquisition, Writing-review & editing. Salamatu Osman: Investigation, Formal analysis, Writing-original draft. All authors reviewed and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this article.

Declarations

Ethics approval and consent to participate

All procedures performed in studies involvinghuman participants have been approved by the Human Research Publication andEthics Committee, Kwame Nkrumah University of Science and Technology, Ghana.Moreover, written consent was sought from the panelists partaking in thesensory evaluation of the cookies products. The panelists were informed thatparticipation was completely voluntary and any participant can decide to withdrawfrom the research at any time without giving reason(s) for the action.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competinginterests.

Author details

[1]Department of Food Science and Technology, Faculty of Agriculture, Food and Consumer Sciences, University for Development Studies, Post Office Box TL 1882, Nyankpala Campus, Tamale, Ghana. [2]Department of Agricultural Mechanization and Irrigation Technology, Faculty of Agriculture, Food and Consumer Sciences, University for Development Studies, Post Office Box TL 1882, Nyankpala campus, Tamale, Ghana.

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