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Physical characteristics, nutritional composition and acceptability of gluten-free crackers produced from germinated pearl millet (*Pennisetum glaucum*), defatted-sesame seed (*Sesamum indicum*) and defatted-tigernut (*Cyperus esculentus*) composite flours

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Abstract

Crackers are flat, crispy, baked snacks typically prepared from wheat flour. Recently, increasing efforts are being made towards the use of novel ingredients with health, economic and nutritional benefits in the production of crackers. In this study, physical, chemical and sensory characteristics of gluten-free crackers (GFCs) developed from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours (90:0:10, 80:10:10, 70:20:10, 60:30:10) against those of 100% wheat cracker (WHFC) were investigated. Compared to wheat flour, formulated composite flours demonstrated higher water and oil absorption capacities but swelling indices were comparable. While WHFC showed higher ($P < 0.05$) colour characteristics (*L**, *a** and *b**) as well as higher weight, thickness and diameter, the GFCs exhibited improved spread ratio. The developed GFCs were also higher in ash (2.41–2.71%), fibre (3.63–4.18%), protein (9.14–12.21%), and energy (376.82–381.58 kCal/100 g) but lower in carbohydrates (67.60–69.76%). Phytates were generally low in all the crackers, whereas WHFC showed highest trypsin inhibitors (8.8 mg/100 g). GFCs containing defatted-sesame seeds had the highest calcium (2.81 mg/100 g) and lowest iron (0.17 mg/100 g) contents, respectively. In vitro protein digestibility was generally higher ($P < 0.05$) in the developed GFCs than wheat cracker. Mean sensory scores of > 6 on a 9-point Hedonic scale indicated that the GFCs were generally accepted by the panellists. The study revealed the potentials of composite flours prepared from germinated pearl millet, defatted-sesame seed, and defatted-tigernut flours in the production of acceptable, nutritious and healthy crackers.

Keywords Composite flour · Cracker snack · Pearl millet · Processing method · Quality attributes · Sesame seeds

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1 Introduction

The popular and increasing consumption of snacks among people of all ages has continued to give ready-to-eat snack products an edge in the food industry worldwide. While the rising trend in snacks' consumption can be attributed to their low manufacturing cost, convenience, long-shelf life and ability to serve as a vehicle of important nutrients [1], consumers' changing lifestyle constitutes another crucial factor. However, more research is required to meet consumers' increasing demands for more nutritious and functional snacks, as most of the current snacks are being regarded as junks with high amount of fats, sugar, salt and minor amount of dietary fibre.

Crackers are flat, dry, baked, crispy snacks typically made of wheat flour which is often appreciated for its unique gluten protein content. They contain little sugar, a moderate amount of fat, and relatively low levels of salt and are therefore a better alternative to sweeter and oil-filled snacks [2–4]. Crackers are considered a healthy snack option and one of the most desirable snacks owing to their good eating quality, shelf stability and superior nutritional properties [3]. Notwithstanding, considering the negative economic impact of wheat importation on low or non-wheat producing countries, poor wheat protein quality attributable to lysine deficiency and the correlation of wheat protein to celiac disease in gluten sensitive people [5], research effort is being focused on the partia or total substitution of wheat flour with underutilized locally grown crops including oat, acha, pigeon pea, coconut, bambara groundnut, sesame and quinoa in the preparation of functional, nutritious and acceptable ready-to-eat snacks particularly crackers [2–4, 6, 7]. Another example of such lesser known locally grown crops of interest that has the potential to contribute to food security of the developed and developing nations of the world is pearl millet.

Pearl millet (*Pennisetum glaucum*), a cereal belonging to the grass family, *Poaceae* is the most widely grown specie in the arid and semi-arid tropical areas of India and Africa. It is adaptable to harsh weather conditions and accounts for half of the world's millet production [8, 9]. In many African countries, it is often consumed as steam-cooked products (couscous), thick and thin porridges (*ogi*), and as an ingredient in the brewery industry for beer production. It is nutritionally better than many other cereal crops such as corn and sorghum due to its high-quality protein (11.6–11.8%) and high levels of minerals such as phosphorus (296 mg/100 g), and zinc (3.1 mg/100 g) [10]. It has also been shown to exhibit high antioxidant activity and contains high bioactive components such as phenolic compounds and ascorbic acid [11]. Being gluten-free, pearl millet is a promising alternative to wheat in an attempt to prevent the risk of celiac disease and enhance the utilization of locally grown crops. Furthermore, germinated pearl millet flour was reported to be significantly higher in crude protein content, as well as water and oil absorption capacities than their roasted and fermented counterparts [8], thereby making germination a more suitable processing method for obtaining high quality pearl millet flour that could be further used in food production. However, the relatively low nutritional value of cereal meals such as pearl millet meal calls for the inclusion of protein sources like legumes to develop a more nutritious meals that can be useful in combating protein-energy malnutrition (PEM).

Sesame (*Sesamum indicum*), an erect herbaceous annual plant belonging to the family *Pedaliceae*, is one of the oldest oilseed crops widely grown in Africa and Asia. The seeds are commonly added to certain foods to provide a nutty flavour and crunchy texture [12]. The seeds are rich in fat, protein, vitamins, antioxidants, dietary fibre and minerals such as iron and calcium. Its traditionally extracted oil has been reported to be rich in unsaturated fatty acids, amino acids, fat-soluble vitamins, etc. [12]. Sesamin, sesamolin, sesamol, sesaminol and some other natural lignans in sesame seeds have been shown to possess various pharmacological effects such as anti-hypertensive, anti-inflammatory, anti-cancer, antioxidant, anti-melanogenic, anti-cholesterol, auditory protection and other strong bioactive effects [12]. After extraction of oil from the seed flour, the defatted sesame flour contains about 9% moisture content, 50% crude protein, 1.5% fat and has high water absorption capacity of about 340% [13]. This defatted sesame flour also contains a balanced amino acid composition of proteins especially methionine and tryptophan, dietary fibre, and important bioactive compounds with antioxidant activity and health-promoting effects [13, 14]. Sesame seeds are therefore a good ingredient for baked foods formulation due to its high water absorption capacity, good sensory qualities, high quality protein and health promoting-active ingredients.

Besides the supplementation of cereal meals with protein sources, other plant materials like tigernut which have characteristic functional components like fibre can be used in enhancing the health benefits of the cereal-based foods. Tigernut (*Cyperus esculentus*) belongs to the family, *Cyperaceae* and it is a grass-like plant that produces rhizomes with spherical-like tubers. This plant was discovered some 4000 years ago [15]. The tuber is a rich source of dietary fibre which has been found to be effective in the treatment and counteractive action of numerous sicknesses including colon cancer, heart diseases, obesity, diabetics and gastrointestinal disorders [16]. It has also been shown

to be a rich source of valuable oil and contains a moderate quantity of protein. Additionally, it is an excellent source of some important minerals such as potassium, iron and calcium which are essential for body growth and development [17]. Defatting of tigernut flour has been shown to improve its crude protein, fibre, ash, sugars, minerals, oil and water absorption capacities [18]. Tigernut tubers could therefore be employed as a gluten-free functional ingredient in food formulation.

Currently, consumers are more concerned about their health, and therefore demand inexpensive food products that provide health benefits in addition to satisfaction and the required nutrients. Moreover, evidence of diseases such as high blood pressure, diabetes and cardiovascular diseases among other illnesses as a result of lifestyle changes are on the rise. These have continued to increase the consumers' demand for functional snacks. Crackers made from dehulled oat and pea protein isolate [4], blends of acha and blanched pigeon pea [6] and defatted chia flour, wheat germ, oat and quinoa [7] have been shown to possess bioactive components that could help in the prevention and management of certain degenerative diseases like diabetes. Therefore, as part of the strategy to meet the consumers' demand for functional foods and bypass the economic, nutritional and health limitations of wheat usage in food formulation, the physicochemical and sensory attributes of crackers developed from germinated pearl millet, defatted-sesame seed, and defatted-tigernut composite flours were investigated in this study.

2 Materials and methods

2.1 Materials

Pearl millet grains, sesame seeds (white variety), tigernut tubers (yellow variety), white wheat flour (all purpose), margarine, sugar, salt and baking powder were purchased from *Ipata* market in Ilorin, Kwara State, Nigeria. Xanthan gum which was used as the binder was gotten from Mart rite in Ilorin. All chemicals and the equipment used were of analytical grade.

2.2 Production of germinated pearl millet, defatted-sesame seed and defatted-tigernut flours

Pearl millet grains were sorted, rinsed, soaked in distilled water (1:2 w/v) at room temperature (27 ± 1 °C) overnight, germinated and processed into flour according to the method described by Sade [8]. Sesame seeds were sorted, rinsed, soaked in distilled water (1:4 w/v) at room temperature overnight, dehulled, drained, dried at 60 °C (Gallenkamp Oven B.S. Model OV-250, Size 2, Manchester, UK) for 12 h, defatted and processed into flour according to the method described by Gandhi and Srivastava [13] with little modifications. Cold extraction method using food grade N-hexane (1:4 w/v) for 3 h with constant stirring was employed in defatting the seeds. The seeds were then dried in a cabinet drier (Gallenkamp Oven BS Model OV-250, Size 2, Manchester, UK) at 60 °C until constant weight was obtained after which they were milled to a fine flour.

Tigernut tubers were sorted out to remove foreign materials, damaged and spoilt ones. The sorted tigernut tubers were rinsed with clean water, spread on clean flat aluminum trays and placed in a cabinet dryer set at 70 °C for 2 h. Thereafter, they were milled into flour and the oil was extracted with food grade N-hexane in continuous soxhlet extraction apparatus for 3 h. The defatted flour produced was then oven-dried (Gallenkamp Oven B.S. Model OV-250, Size 2, Manchester, UK) at 50 °C for 10 h for complete solvent removal. The resultant flours were packaged separately in airtight plastic containers for later use.

2.3 Formulation of germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

Four composite flours containing different ratios of germinated pearl millet flour and defatted-sesame seed flour but equal quantity of defatted-tigernut flour, were formulated as shown in Table 1. In addition, 100% wheat flour (WHF) was used as the control.

2.4 Determination of particle size distribution of germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

Fifty grams (50 g) of each flour was sieved through a set of vertically stacked sieves with mesh sizes of 425 µm, 250 µm, 90 µm and 75 µm using a Retsch Vibro shaker (Model 65056, W. Germany) set at frequency of 50 Hz for 10 min. The retained fractions on each sieve were then weighed and recorded.

Table 1 Germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours' formulation

Sample	Germinated pearl millet flour (%)	Defatted-sesame seed flour (%)	Defatted-tigernut flour (%)
PS_0T	90	0	10
PS_1T	80	10	10
PS_2T	70	20	10
PS_3T	60	30	10

100% Wheat flour (WHF) served as the control

2.5 Determination of functional properties of germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

2.5.1 Bulk densities

The loose (LBD) and packed bulk densities (PBD) of each flour sample was determined following the method described by Falade and Akeem [19]. Briefly, 5 g of each sample was weighed into a 25 ml graduated glass measuring cylinder and the volume was recorded. Then, the measuring cylinder was gently tapped on the bench top 100 times and the volume was also recorded. The loose and packed bulk densities were then calculated as established in Eqs. 1 and 2.

$$\text{Loose bulk density}\,(\text{g/ml}) = \frac{\textit{Weight of sample}}{\textit{Volume of sample before tapping}} \tag{1}$$

$$\text{Packed bulk density}\,(\text{g/ml}) = \frac{\textit{Weight of sample}}{\textit{Volume of sample after tapping}} \tag{2}$$

2.5.2 Swelling index

Each of the flour samples (1 g) was separately filled into a 10 ml graduated measuring cylinder and the volume occupied was recorded after gently leveling it. Distilled water (5 ml) was carefully added to the flour without agitation and the mixture was allowed to stand undisturbed for 30 min. The change in volume after swelling was then recorded. The ratio of the final volume to the original volume occupied by the sample was taken as the swelling index [20].

2.5.3 Water and oil absorption capacities

The procedures described by Abbey and Ibeh [21] were adopted with little modification. For water absorption capacity (WAC), 1 g of each flour sample was weighed into a 50 ml centrifuge tube and 10 ml of distilled water was added. The tube containing the sample was then shaken by hand and allowed to stand at room temperature (27 ± 1 °C) for 30 min. The mixture was centrifuged (D-3756 Osterode AM Harz model 4515 Sigma, Germany) at 3000 rpm for 30 min. Then, excess water was decanted by inverting the tubes and the difference between initial volume of distilled water added to the sample and the volume obtained after decantation was determined. The oil absorption capacity (OAC) was determined following the same procedure, except that olive oil was used in place of distilled water. The loose and packed bulk densities were then calculated as shown in Eqs. 3 and 4.

$$\text{Water absorption capacity}\,(\text{ml/g}) = \frac{\text{Volume of water absorbed}}{\text{Weight of sample}} \tag{3}$$

$$\text{Oil absorption capacity}\,(\text{ml/g}) = \frac{\text{Volume of oil absorbed}}{\text{Weight of sample}} \tag{4}$$

2.6 Crackers' production from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

The method described by Han et al. [2] was modified to produce crackers from wheat flour and the formulated composite flours in Table 1. Briefly, the recipe used were flour (100 g), sugar (27 g), fat (9 g), salt (1 g), baking powder (1 g), water (50 ml) and xanthan gum (0.2 g). All the dry ingredients excluding sugar were mixed and liquid ingredients and sugar were also mixed separately for 30 s. The dry ingredients blend was gradually poured into the liquid emulsion being stirred continuously to form a dough. The dough was rested for 10 min followed by sheeting, laminating, cutting and baking of the dough in an electric oven (Emel electric oven, Model EOV-9L, China) at 175 °C for 4 min. The resulting crackers were cooled to room temperature. Fine soft wheat flour was used for preparation of control crackers.

2.7 Physicochemical properties of the developed gluten-free crackers

2.7.1 Objective colour determination

Colour measurement of the crackers was carried out using a Hunter Colourimeter fitted with optical sensor (Hunter Associates Laboratory Inc., Reston, VA, USA) on the basis of CIE $L^* a^* b^*$ colour system where L^* value measures black to white (0–100), a^* measures redness when positive and green when negative and b^* measures yellowness when positive and blue when negative [18]. The total colour difference (ΔE^*) was calculated as shown in Eq. 5 [22].

$$\Delta E* = \sqrt{\Delta a *^2 + \Delta b *^2 + \Delta L *^2} \tag{5}$$

2.7.2 Size-related properties of the crackers

The weight, diameter, thickness and spread ratio of the crackers were determined using the method described by Oyeyinka et al. [23].

2.7.3 Proximate analysis and calorie determination of the crackers

Moisture, crude protein, crude fat, total ash, crude fibre and carbohydrate contents were determined using the standard methods of AOAC [24]. Briefly, oven drying method at 105 °C for moisture determination, micro-Kjeldahl method (6.25 × N) for crude protein, soxhlet extraction method for crude fat estimation, total ash was obtained by igniting 2 g sample at 550 °C for 4 h using muffle furnace, crude fibre was determined using digestion method and carbohydrate was estimated by difference [100 – (% water + % protein + % fat + % ash + % crude fibre)].

Energy value of the crackers was determined using the Atwater Formula presented in Eq. 6 [20].

$$\text{Energy value (kCal/100g)} = (\%\ \text{protein} \times 4) + (\%\ \text{fat} \times 9) + (\%\ \text{carbohydrate} \times 4) \tag{6}$$

2.7.4 Anti-nutritional analysis of the crackers

Phytate content of the crackers was evaluated using the method described by Wheeler and Ferrel [25] while the trypsin inhibitor content was determined according to the method described by Raj Bhandari and Kawabata [26]. Briefly, 4 g of each sample was soaked in 100 ml of 2% HCl for 3 h and filtered through Whatman No. 2 filter paper. A 25 ml of the filtrate was placed in a conical flask after which 5 ml of 0.3% ammonium thiocyanate solution and distilled water (53.5%) were added. The mixture was titrated against a standard iron (III) chloride solution until a brownish yellow colour persisted for 5 min. The phytate content was expressed in mg/100 g of the sample. For the trypsin inhibitor, 1 g of each cracker sample was shaken with 50 mL of 10 M NaOH. The pH of the resulting slurry was adjusted to between 9.4 and 9.6 with 1 M NaOH or 1 M HCl. The slurry was shaken and stirred at ambient temperature for 3 h. After extraction, the clear suspension was used for inhibitor estimation. The following additions were pipetted into a series of 10 ml tubes: (a) reagent blank: 2 ml deionized water; (b) standard (40 mg trypsin): 2 ml standard trypsin solution, 2 ml deionised water; (c) sample blank: 1 ml sample extract, 1 ml of deionized water; (d) sample: 1 ml sample extract, 1 ml deionized water, 2 ml standard trypsin solution. After mixing and preheating to 37 °C for 10 min, 5 mL of Benzoyl-DL-arginine-*p*-nitroanilide hydro-chloride solution

which has been warmed to 37 °C was pipetted into each tube and mixed. After 10 min incubation at 37 °C, each tube received 1 ml acetic acid (30% v/v) to stop the reaction. Standard trypsin (2 ml) was then added to the reagent blank (a) and sample blank (c) tubes. After centrifugation, the absorbance of the clear solutions was measured at 410 nm using spectrophotometer (Jenway 7305, Bibby Scientific, London, UK) and the trypsin inhibitor was expressed in mg/100 g of the sample.

2.7.5 Determination of calcium and iron contents of the crackers

The calcium and iron contents of the crackers were evaluated according to the method described by Oyeyinka [27]. Briefly, each of the samples (1 g) was dried at 105 °C for 2 h and ashed in a muffle furnace at 600 °C for 5 h. The ash was hydrated with 2 ml of deionized water followed by addition of 2 ml concentrated HCl. The mixture was diluted with 20 ml of deionized water before being boiled in a water bath till dry. Hydration of the remaining ash was carried out with 10 ml of 10% HCl followed by boiling and refluxing for 5 min. The resulting mixture was then filtered into a 10 ml volumetric flask and was made to mark with deionized water. Iron and calcium were determined from standard curves generated from different concentrations of their respective standards using a spectrophotometer (Jenway 7305, Bibby Scientific, London, UK) at wavelengths of 248.3 nm and 422.7 nm, respectively.

2.8 In vitro protein digestibility of the crackers

The in vitro protein digestibility of the crackers was carried out using trypsin enzyme following the method described by Mohamed et al. [28]. Each of the sample (20 mg) was digested in triplicates in 10 ml of trypsin (0.2 mg/ml in 100 mM Tris-buffer pH 7.6). The suspension was incubated at 37 °C for 2 h. Five millilitres (5 ml) of 50% trichloroacetic acid (TCA) was added to stop hydrolysis. The mixture was allowed to stand for 30 min at 4 °C prior to centrifugation at 9500×*g* for 14 min using a D-3756 Osterode AM Harz model 4515 centrifuge (Sigma, Germany). The resultant precipitate was dissolved in 5 ml of NaOH and protein concentration was measured using the Kjedahl method. Digestibility was calculated as shown in Eq. 7.

$$\text{In vitro protein digestibility (\%)} = \frac{(A - B)}{A} \times 100 \tag{7}$$

A is the Total protein content (mg) in the sample, B is the Total protein content (mg) in TCA precipitate.

2.9 Sensory evaluation of the crackers

Sensory qualities of the crackers were evaluated following the description of Arise et al. [5]. The sensory attributes (appearance, aroma, crispiness, taste and overall acceptability) of the crackers were evaluated by a 50-member semi-trained panel (average age of 27 years, comprising 23 males and 27 females) recruited among the students and members of staff of the University of Ilorin. The selected members were accustomed to eating crackers and were familiar with the quality characteristics of crackers. Also, screening was done to ascertain their interest and ability to differentiate cracker sensory properties. The coded cracker samples alongside a questionnaire were randomly presented to each assessor in a well illuminated booth and portable water was also provided for rinsing mouth after each taste assessment. A 9-point hedonic preference scale (1—dislike extremely, 2—dislike very much, 3—dislike moderately, 4—dislike slightly, 5—neither like nor dislike, 6—like slightly, 7—like moderately, 8—like very much, 9—like extremely) and a multiple comparison test were adopted for the assessment.

2.10 Statistical analysis

All experiments were conducted in triplicates except where it is stated otherwise. The data generated were subjected to Analysis of Variance (ANOVA) and means were separated using Duncan's Multiple Range Test ($P < 0.05$). Statistical Package for Social Sciences (SPSS, version 16.0) was used and the results were expressed as mean ± standard deviation.

3 Results and discussion

3.1 Particle size distribution of germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

The particle size of the germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours varied significantly ($P < 0.05$) when compared with 100% wheat flour, which was used as the control. Majority of the particles of the flours samples were retained on the sieve with mesh size of 90 µm, with the highest fraction recorded for wheat flour (Table 2). This result indicated that wheat flour was relatively finer than the composite flours. Inclusion of defatted-sesame seed flour affected ($P < 0.05$) the particle size distribution of the composite flours but the results followed no particular trend. This is similar to the observation reported on particle size distribution of gari from frozen cassava root [29]. The extent of starch damage during processing such as milling and freezing has been suggested as a major factor influencing the particle size distribution of food materials like wheat flour and gari [29, 30]. This is also applicable in this study but since the flour samples except the wheat flour were subjected to the same milling process, crop type and differences in flour composition could therefore be considered major contributory factors to the variation in particle sizes of the composite flours. Particle size affects the bulk density of flours and consequently influences the compressibility of flour samples [19]. Similarly, it has been established in the literature that particle size affects the functional and physicochemical properties of food materials as well as the quality of the final products [31].

3.2 Functional properties of germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

The functional properties of the flour samples are presented in Fig. 1. The loose (0.32–035 g/ml) and packed bulk density (0.58–0.68 g/ml) of the composite flours were lower ($P < 0.05$) than those of the wheat flour sample. The decrease could be attributed to the larger particle sizes of the composite flours as observed in Table 2. This is plausible since the individual particle mass, size, property, density and geometry have been reported as the major factors that could influence bulk densities of a food materials [20]. This is also the most likely reason for the decrease in the loose and packed bulk densities of the composite flours with increase in the level of substitution of the defatted-sesame seed. The decrease in bulk density of the composite flours could enhance their food applications in complementary foods' formulations [32]. On the contrast, low bulk density of flour is an indication of more space requirement during packaging. The knowledge of bulk densities of flours is also essential in determining their flow characteristics for effective handling [19].

The swelling index of the composite flours except sample PS_3T were higher ($P > 0.05$) than that of the wheat flour (1.29). Although the results of the swelling index of the flour samples did not follow a particular trend, the lowest ($P < 0.05$) swelling index was recorded for the composite flour sample containing 30% defatted-sesame seed (PS_3T). The swelling index is the measure of starch ability to absorb water and swell at room temperature. It is also associated with binding within the starch granules of the micelle network [20]. Starch content, pre-treatment, processing history and presence of other components such as lipids and proteins have been suggested as factors that could influence swelling index [33]. Variation in the swelling index of the flour samples might have therefore resulted from different degree of associative forces in their starch granules and interactive effects of other macromolecules.

Table 2 Particle size distribution (%) of germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

Sample	425 µm	250 µm	90 µm	75 µm	Fine particle
WHF	0.00 ± 0.00^{e}	0.43 ± 0.00^{e}	80.13 ± 0.05^{a}	9.89 ± 0.02^{a}	9.54 ± 0.03^{a}
PS_0T	5.64 ± 0.01^{d}	37.40 ± 0.00^{b}	52.61 ± 0.09^{b}	2.30 ± 0.00^{d}	2.02 ± 0.01^{a}
PS_1T	7.48 ± 0.01^{c}	39.24 ± 0.01^{a}	45.93 ± 0.07^{e}	4.02 ± 0.01^{c}	3.31 ± 0.01^{a}
PS_2T	9.80 ± 0.01^{b}	34.14 ± 0.06^{c}	47.23 ± 0.07^{d}	5.05 ± 0.01^{b}	3.75 ± 0.02^{a}
PS_3T	12.28 ± 0.02^{a}	31.23 ± 0.01^{d}	49.99 ± 0.01^{c}	4.90 ± 0.01^{b}	1.58 ± 0.02^{a}

Values are means ± SD (n = 3); Means with different superscript along a column are significantly different ($P < 0.05$)

WHF 100% Wheat flour, *PS_0T* 90% Pearl millet + 0% Sesame seed flour + 10% Tigernut flour, *PS_1T* 80% Pearl millet + 10% Sesame seed flour + 10% Tigernut flour, *PS_2T* 70% Pearl millet + 20% Sesame seed flour + 10% Tigernut flour, *PS_3T* 60% Pearl millet + 30% Sesame seed flour + 10% Tigernut flour

The water absorption capacity (1.73–2.12 ml/g) of the processed pearl millet, defatted-sesame seed and tigernut composite flours were higher ($P < 0.05$) than that of the wheat flour (0.92 ml/g). The lowest water absorption capacity obtained for wheat flour could be attributed to the compactness of its structure compared to the composite flours, having a loose structure of starch polymers. The higher water absorption capacity of the composite flours compared to wheat flour could also be linked to the processing history of the flour, presence of more hydrophilic components such as fibre, proteins, carbohydrate and lower lipophilic components in their constituent raw materials. Adegunwa et al. [34] observed similar trend and gave similar assertion for the water absorption capacity of wheat flour substituted with cashew apple fiber composite flour. Generally, the water absorption capacity of the composite flours increased with increase in the level of substitution of the defatted-sesame seed. This could be due to the high protein composition, fibre content and water absorption capacity of the defatted sesame flour [12, 13]. Similar results have been reported by Dauda et al. [35] and Julianti et al. [36] upon addition of oily seed flours to wheat flour. The high water absorption capacity recorded for the germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours is an indication of their suitability for the development of baked food products and other similar applications.

Oil absorption capacity is the ability of flour to absorb oil, which acts as flavour retainer, increases the mouth feel characteristics and improves palatability in bakery or meat products where fat absorptions are desired [37]. The results of the oil absorption capacity of the flour samples followed similar trend with those of water absorption capacity. Hence, the wheat flour had the lowest water absorption capacity (1.83 ml/g) while the composite flour containing 30% defatted-sesame seeds had the highest (2.53 ml/g). The most probable justification for the high oil absorption capacity of the composite flours compared to wheat flour is the addition of defatted-tigernut and defatted-sesame seeds. This justification is in line with the findings of Falade and Akeem [19] where defatting of *Prosopis africana* flour was observed to increase its oil and water absorption capacities. Similar increase in the oil and water absorption capacities of tigernut flour following defatting process has been reported [18]. The alteration in the seeds' composition and nutritional components' conformation could be responsible for this observation. These results compare favourably with the findings of Awolu et al. [38] on flour blends of rice, cassava and kersting's groundnut. The high oil absorption capacity of the composite flours would make them useful in formulation of foods such as soups mixes and other similar applications that require high oil absorption property.

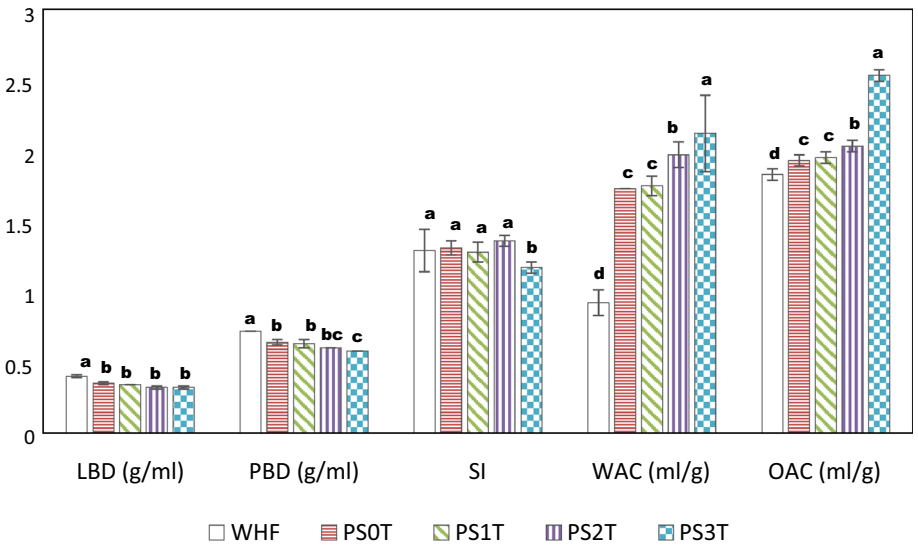


Fig. 1 Functional properties of germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours. Error bars indicate standard deviation (N = 3). Charts with different alphabet are significantly different ($P < 0.05$). *LBD* Loose bulk density, *PBD* Packed bulk density, *SI* Swelling index, *WAC* Water absorption capacity, *OAC* Oil absorption capacity, *WHF* 100% Wheat flour, PS_0T 90% Pearl millet + 0% Sesame seed flour + 10% Tigernut flour, PS_1T 80% Pearl millet + 10% Sesame seed flour + 10% Tigernut flour, PS_2T 70% Pearl millet + 20% Sesame seed flour + 10% Tigernut flour, PS_3T 60% Pearl millet + 30% Sesame seed flour + 10% Tigernut flour

3.3 Colour and physical appearance of the crackers

Colour is an essential food quality parameter and processing as well as plant composition especially with respect to pigments have been suggested as colour influencing factors [19]. The objective colour measurement of the crackers indicated that lightness (L^*), redness (positive a^*), and yellowness (positive b^*) values of the wheat crackers were significantly ($P < 0.05$) higher than those of the developed crackers from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours (Table 3). The relatively darker colour of the developed crackers could also be noticed in their physical appearance (Fig. 2). The lower values recorded for the L^*, a^* and b^* of the developed crackers could be attributed to differences in flour compositions (Table 1). The relatively darker colour of the developed crackers might be due to sugar caramelization and Maillard reaction between the amino and carbonyl groups of protein and carbohydrate, respectively [39]. This is plausible since the composite flours are substantially made up of protein and carbohydrate rich crops. Aside ingredients' composition, other factors that may affect colour characteristics include time of baking and atmospheric conditions [40]. Similar observations have been reported by Alobo [41] for millet-defatted sesame flour blends' biscuits and Waleed et al. [42] for biscuits produced from millet-lentil flour blends.

The results of the objective colour measurement also showed that the differences in colour attributes L^*, a^*, b^* and ΔE^* of the developed crackers were not significant (Table 3). However, the slight variation among the colour attributes of the developed crackers could be due to the differences in their flour composition (Table 1). Also, the high total colour difference ($\Delta E^* > 3$) of the developed crackers indicated that they were very distinct from the control wheat crackers and the implication of this is that consumers might easily perceive the colour difference between the wheat cracker and the developed gluten-free crackers.

3.4 Size-related properties of the crackers

The results of the size-related properties showed that the developed crackers had significantly ($P < 0.05$) lower weight (8.52–10.61 g), diameter (4.05–5.05 g) and thickness (0.53–0.75 g) but higher spread ratio (5.05–7.65) than the control wheat crackers (Table 4). The absence of gluten appears to play a major role in the reduction of weight, diameter, and thickness due to lower viscoelasticity and poor air entrapment. Significant differences existed among the size-related properties of the developed gluten-free crackers. There was a general decrease in the weight, diameter and thickness of the developed crackers with increasing level of defatted-sesame seed flour. The reducing bulk densities (Fig. 1) of the composite flours which were also related to their high fibre (Table 5) could account for the decreasing weight of the developed crackers. Similar observations and assertions have been reported by Alobo [41] for millet-defatted sesame seed biscuits, Ayo et al. [15] for acha-tigernut biscuits and Arise et al. [5] for wheat cookies supplemented with Bambara protein isolate and ripe banana mash. Decrease in diameter and thickness of wheat cookies supplemented with Bambara protein isolate and ripe banana mash has been attributed to gluten reduction and weak gluten network to trap air [5]. The study of Mihiranie et al. [3] also showed a general decrease in the diameter and thickness of crackers produced from wheat and defatted coconut flour. However, the high water absorption capacities of the composite flours (Fig. 1) were expected to enhance the thickness of the crackers in this study. It could therefore be suggested that while the absence

Table 3 Colour of crackers made from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

Sample	L^*	a^*	b^*	ΔE^*
WHFC	48.40 ± 0.91^a	4.50 ± 0.72^a	16.62 ± 0.93^a	
PS_0TC	41.46 ± 0.45^b	1.34 ± 0.28^b	10.66 ± 0.31^b	9.75 ± 2.16^b
PS_1TC	41.69 ± 0.59^b	1.43 ± 0.43^b	10.72 ± 0.45^b	9.46 ± 2.30^b
PS_2TC	41.56 ± 0.16^b	1.28 ± 0.04^b	10.56 ± 0.11^b	9.69 ± 1.65^b
PS_3TC	42.20 ± 0.06^b	1.86 ± 0.11^b	11.21 ± 0.02^b	8.65 ± 1.43^b

Values are means ± SD (n = 3); Means with different superscript along a column are significantly different ($P < 0.05$)

WHFC 100% Wheat flour cracker, *PS_0TC* 90% Pearl millet + 0% Sesame seed flour + 10% Tigernut flour cracker, *PS_1TC* 80% Pearl millet + 10% Sesame seed flour + 10% Tigernut flour cracker, *PS_2TC* 70% Pearl millet + 20% Sesame seed flour + 10% Tigernut flour cracker, *PS_3TC* 60% Pearl millet + 30% Sesame seed flour + 10% Tigernut flour cracker, L^* colour lightness, a^* red (+)/green (–), b^* yellow (+)/blue (–), ΔE^* total colour difference

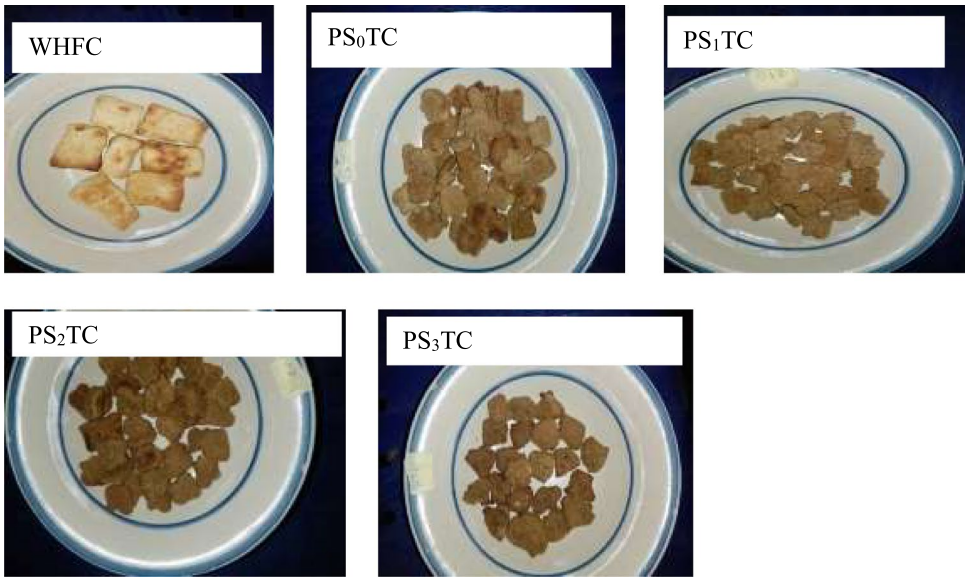


Fig. 2 Physical appearance of the developed gluten-free crackers. *WHFC* 100% Wheat flour cracker, *PS_0TC* 90% Pearl millet + 0% Sesame seed flour + 10% Tigernut flour cracker, *PS_1TC* 80% Pearl millet + 10% Sesame seed flour + 10% Tigernut flour cracker, *PS_2TC* 70% Pearl millet + 20% Sesame seed flour + 10% Tigernut flour cracker, *PS_3TC* 60% Pearl millet + 30% Sesame seed flour + 10% Tigernut flour cracker

of gluten is responsible for the lower diameter and thickness of the developed crackers, the high fibre composition of the composite flours (Table 5) is most likely responsible for the decreasing diameter and thickness of the developed crackers with increasing level of defatted-sesame seed flour. It was also observed that with increasing level of defatted-sesame seed flour, spread ratio of the crackers increased. Similar observations have been reported for cereal-based biscuits supplemented with defatted-sesame seed [41], tigernut flour [15] and crackers produced from wheat and defatted coconut flour [3]. High spread ratio which is often influenced by dough flow and expansion, is a desirable quality attribute of crackers. Viscosity determines the dough flow, and an inverse relationship exists between the spread ratio and dough viscosity. Furthermore, it has been suggested that high protein flour would give product with low spread ratio [23]. The increase in spread ratio with increasing protein content (Table 5) of the developed crackers in this study suggested that other food constituents such as fat and fibre are major contributory factors to the spread ratio. This is plausible because while the high fibre content could have decreased the viscosity and therefore enhanced the spread ratio of the paste, the lowest fat composition (5.38%) recorded for the crackers containing 20% defatted-sesame seed (Table 5) could be responsible for the slight reduction in their spread ratios in comparison with the crackers containing 10% defatted-sesame seed.

3.5 Nutritional composition of the crackers

Table 5 shows the moisture (6.46–8.78%), crude fat (5.38–7.64%), ash (2.38–2.71%), fibre (3.54–4.18%), protein (8.05–12.21%), carbohydrate (67.60–72.96%) and energy (374.58–381.58 kCal/100 g) contents of crackers produced from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours. The higher moisture content obtained for the gluten-free crackers containing 10% (PS_1TC) and 20% (PS_2TC) defatted-sesame seed flour could be

Table 4 Size-related properties of crackers made from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

Sample	Weight (g)	Diameter (cm)	Thickness (cm)	Spread Ratio
WHFC	16.83 ± 0.04^{a}	5.19 ± 0.01^{a}	1.03 ± 0.00^{a}	5.05 ± 0.04^{d}
PS_0TC	10.61 ± 0.36^{b}	5.05 ± 0.00^{b}	0.75 ± 0.00^{b}	6.73 ± 0.01^{c}
PS_1TC	9.51 ± 0.57^{c}	4.65 ± 0.07^{c}	0.64 ± 0.01^{c}	7.27 ± 0.08^{b}
PS_2TC	9.17 ± 0.08^{cd}	4.09 ± 0.06^{d}	0.57 ± 0.01^{d}	7.18 ± 0.18^{b}
PS_3TC	8.52 ± 0.01^{d}	4.05 ± 0.00^{d}	0.53 ± 0.01^{de}	7.65 ± 0.08^{a}

Values are means ± SD (n = 3); Means with different superscript along a column are significantly different ($P < 0.05$)

WHFC 100% Wheat flour cracker, *PS_0TC* 90% Pearl millet + 0% Sesame seed flour + 10% Tigernut flour cracker, *PS_1TC* 80% Pearl millet + 10% Sesame seed flour + 10% Tigernut flour cracker, *PS_2TC* 70% Pearl millet + 20% Sesame seed flour + 10% Tigernut flour cracker, *PS_3TC* 60% Pearl millet + 30% Sesame seed flour + 10% Tigernut flour cracker

Table 5 Nutritional composition of crackers made from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

Parameters	WHFC	PS_0TC	PS_1TC	PS_2TC	PS_3TC
Moisture content (%)	7.47 ± 0.03^{c}	7.20 ± 0.04^{d}	8.32 ± 0.04^{b}	8.78 ± 0.02^{a}	6.46 ± 0.04^{e}
Crude fat (%)	5.62 ± 0.01^{d}	7.34 ± 0.02^{b}	7.64 ± 0.02^{a}	5.38 ± 0.02^{e}	6.32 ± 0.02^{c}
Total ash (%)	2.38 ± 0.02^{d}	2.41 ± 0.02^{cd}	2.47 ± 0.03^{c}	2.61 ± 0.01^{b}	2.71 ± 0.03^{a}
Crude fibre (%)	3.54 ± 0.00^{d}	4.18 ± 0.02^{a}	$3.64^{c} \pm 0.00^{c}$	3.63 ± 0.00^{c}	4.05 ± 0.03^{b}
Crude protein (%)	8.05 ± 0.02^{e}	9.14 ± 0.02^{d}	$10.34^{c} \pm 0.01^{c}$	10.51 ± 0.02^{b}	12.21 ± 0.03^{a}
Carbohydrate (%)	72.96 ± 0.05^{a}	69.76 ± 0.01^{b}	$67.60^{e} \pm 0.01^{e}$	69.12 ± 0.05^{c}	68.26 ± 0.04^{d}
Energy (kCal/100 g)	374.58 ± 0.24^{e}	381.58 ± 0.25a	380.48 ± 0.15^{ab}	376.82 ± 0.08^{d}	378.72 ± 0.47^{c}
Calcium (mg/100 g)	1.95 ± 0.03^{c}	1.92 ± 0.06^{c}	2.02 ± 0.03^{b}	2.03 ± 0.00^{b}	2.81 ± 0.01^{a}
Iron (mg/100 g)	0.34 ± 0.04^{a}	0.24 ± 0.00^{bc}	0.17 ± 0.01^{d}	0.27 ± 0.00^{b}	0.22 ± 0.01^{c}

Values are means ± SD (n = 3); Means with different superscript along a column are significantly different ($P < 0.05$)

WHFC 100% Wheat flour cracker, *PS_0TC* 90% Pearl millet + 0% Sesame seed flour + 10% Tigernut flour cracker, *PS_1TC* 80% Pearl millet + 10% Sesame seed flour + 10% Tigernut flour cracker, *PS_2TC* 70% Pearl millet + 20% Sesame seed flour + 10% Tigernut flour cracker, *PS_3TC* 60% Pearl millet + 30% Sesame seed flour + 10% Tigernut flour cracker

associated with the higher water absorption capacity and fibre content of their composite flours compared to the control (Fig. 1; Table 5). The lower moisture content recorded for pearl millet-based crackers containing 10% defatted-tigernut flour (PS_0TC) and the crackers containing defatted-tigernut with 30% defatted-sesame seed flour (PS_3TC) suggests the influence of other factors other than fibre, protein and water absorption capacity on the moisture content of the developed gluten-free pearl millet-based crackers. However, the developed crackers could be stored for a long period of time because their moisture contents were below the recommended 10% stated by Arise et al. [5] for long storage stability of food materials. Fat content of the cracker samples varied significantly ($P < 0.05$), indicating the influence of variation in their flours' formulation. However, the values did not follow a particular trend. The highest fat content found in crackers produced from 80% germinated pearl millet, 10% defatted-sesame seed and 10% defatted-tigernut composite flours could be attributed to high fat content of the geminated pearl millet. A fat content as high as 5.6% has been reported for germinated pearl millet flour [8]. Further substitution of pearl millet flour with defatted-sesame seed flour resulted in significant reduction in the fat content of the crackers (Table 5). While fat could act as a flavour retainer and contribute to the energy value of the crackers, low fat could extend their shelf-life by making them less prone to lipid rancidity and it would also enable the consumption of the crackers by those suffering from atherosclerosis and related health issues.

The crude fibre of the developed crackers were significantly higher than that of the control wheat crackers and the highest fibre (4.18%) content was found in crackers produced from 90% germinated pearl millet and 10% defatted-sesame seed composite flour (Table 5). Higher crude fibre content of the developed crackers could be attributed in one hand to the presence of substantial quantities of fibre in the germinated pearl millet [8] and sesame seeds [13], and to the inclusion of tigernut whose fibre content had been reported to increase from 8.79 to 12.20% [18] on the other hand. The ash and protein contents of the developed crackers were higher than those of the control (100% wheat crackers). Among the developed cookies, significant ($P < 0.05$) increase in the ash and protein contents was observed as the substitution level of defatted-sesame seed flour increased. The high content of ash and protein of the ingredients (pearl millet, tigernut and sesame seeds flours) used and the enhancement of these nutrients by the processing methods (germination and defatting) employed could be responsible for these results. This is plausible based on the increase in protein content of pearl millet following germination [8], high ash and increase in protein content of sesame seeds following defatting [13] and the significant increase in ash and protein content of tigernut after defatting [18]. Ash content is an estimation of the overall mineral composition of a food material while the proteins are essential macromolecules for body building, growth and repair. The high ash and protein contents of the developed crackers would make them useful in tackling micronutrient deficiencies and protein malnutrition, most especially among the low-income earners in developing countries.

Carbohydrate forms the largest part of the proximate components of the cracker samples and this could be due to the fact that the major ingredients of the control cracker (wheat flour) and the developed crackers (pearl millet) are cereals. Decrease in carbohydrate content of the germinated pearl millet owing to the utilization of some of the sugars during the growth metabolic activity [8] and the inclusion of defatted-sesame seeds flour in the formulation could be responsible for the lower carbohydrate content of the developed crackers compared to the control wheat crackers. The

significantly ($P < 0.05$) higher energy values obtained for the developed crackers compared to the control wheat cracker is an indication that the developed crackers would contribute more to the daily energy requirements of consumers. Higher fat and protein composition of the developed crackers could account for their higher energy values. The lowest energy value (376.82 kCal/100 g) obtained for the pearl millet-based cracker containing 10% defatted-tigernut flour and 20% defatted-sesame seed flour among the developed crackers could be traced to its lowest fat content (Table 5).

The calcium content of the cracker samples ranged from 1.92 mg/100 g in crackers produced from 90% germinated pearl millet and 10% defatted-tigernut composite flour to 2.81 mg/100 g in crackers produced from 60% germinated pearl millet, 10% defatted-tigernut and 30% defatted-sesame seeds composite flour (Table 5). The inclusion of defatted-sesame seeds flour significantly ($P < 0.05$) increased the calcium content of the developed crackers and as the level of substitution of the defatted-sesame seeds flour increased, the calcium content of the crackers also increased. This suggested the presence of relatively high amount of calcium in the defatted-sesame seeds compared to other ingredients used in the composite flour formulation. The high quantities of calcium reported for sesame seeds by various researchers [12, 13] could be used to justify this assertion. Similar increase in calcium content following increment in the addition of blanched pigeon pea in acha-blanched pigeon pea cracker has been report by Olagunju et al. [6]. Calcium as a macro element in the diet plays an important role in building and maintaining strong and healthy bones and teeth.

The iron contents of the developed crackers did not follow a particular trend but they were lower ($P < 0.05$) than that of the control wheat cracker (Table 5). These unexpected lower iron contents of the developed crackers might be linked to the leaching of minerals during soaking of the germinated pearl millet and defatting of the tigernut tubers and sesame seeds. Iron is an essential microelement that is required for haemoglobin formation and other physiological roles especially in children, pregnant women and lactating mothers [43]. However, diets containing low levels of iron are also suitable for most adults and menopause women. This is because most adults and menopause women tend to have high levels of iron which is a very strong oxidant, resulting in biological stress [44].

3.6 Anti-nutritional content of crackers made from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

Antinutrients are food constituents that interfere with the bioavailability and absorption of nutrients in the body. Phytate is a common constituent in most cereals and it inhibits the absorption and bioavailability of divalent minerals such as calcium by binding with them [43]. The phytate content of the crackers produced from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours ranged from 0.11 mg/100 g to 0.22 mg/100 g and only the phytate content of the crackers produced from 70% germinated pearl millet, 20% defatted-sesame seed and 10% defatted-tigernut composite flours was observed to be significantly ($P < 0.05$) higher than that of the control wheat cracker (Fig. 3). However, the values were lower than the range of 0.23 mg/100 g to 1.63 mg/100 g reported by Olagunju et al. [6] for the phytate content of acha and acha-blanched pigeon pea crackers. Meanwhile, germination of the pearl millet, which is the major ingredient of the developed crackers, could be responsible for the lowest phytate content of the crackers made from 90% pearl millet and 10% tigernut composite flour. This is plausible based on the study of Akeem et al. [43] which reported the ability of germination to reduce phytate content of plant-based foods through the breakdown of phytic acid to lower inositol phosphate that have lower mineral binding ability by the action of the synthesized phytases. Low concentrations of phytic acid and some other antinutrients may have positive effects on human health with a protection against cancer and some other heart diseases [44, 45].

The trypsin inhibitors of the developed crackers (0.62–7.79 mg/100 g) were lower than that of the control wheat cracker (8.87 mg/100 g) (Fig. 3). This might be due to the germination of pearl millet as well as the defatting of the tigernut and sesame seeds used in the production of the crackers. However, the trypsin inhibitor increased among the defatted-sesame seeds flour containing crackers as the level of substitution of the defatted-sesame seeds flour increased. This indicated that sesame seeds contained substantial amount of trypsin inhibitor. Similar observation and assertion have been reported for acha-blanched pigeon pea crackers [6]. Trypsin inhibitor is known to bind protein in food thereby making it unavailable to the body. Considering the low anti-nutritional content of the developed crackers, the bioavailability and absorption of the nutrients are not expected to be a source of concern to the consumers of the developed crackers.

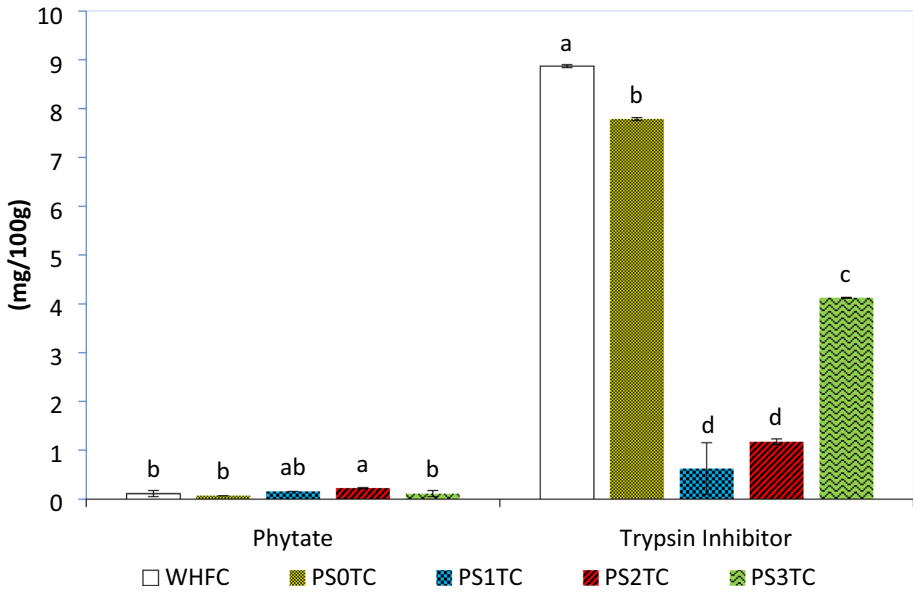


Fig. 3 Anti-nutritional content of crackers made from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours. Error bars indicate standard deviation (N = 3). Charts with different alphabet are significantly different (P < 0.05). *WHFC* 100% Wheat flour cracker, *PS_0TC* 90% Pearl millet + 0% Sesame seed flour + 10% Tigernut flour cracker, *PS_1TC* 80% Pearl millet + 10% Sesame seed flour + 10% Tigernut flour cracker, *PS_2TC* 70% Pearl millet + 20% Sesame seed flour + 10% Tigernut flour cracker, *PS_3TC* 60% Pearl millet + 30% Sesame seed flour + 10% Tigernut flour cracker

3.7 In vitro protein digestibility of crackers made from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

Protein digestibility is one of the best ways to examine the quality of a protein [19]. The in vitro protein digestibility of the cracker samples ranged from 57.47 to 83.31% (Fig. 4). The developed crackers generally exhibited higher (P < 0.05) in vitro protein digestibility than the control wheat cracker. Decrease in the antinutritional factors such as trypsin inhibitor (Fig. 3) that are capable of binding protein in the developed crackers caused by the germination of the pearl millet could be accountable for the higher in vitro protein digestibility of the developed crackers. The significant (P < 0.05) higher in vitro protein digestibility recorded for crackers produced from 90% germinated pearl millet and 10% defatted-tigernut composite flour among the developed crackers could be linked to its lowest phytate composition (Fig. 3) and the relatively low content of other protein-binding antinutrients other than trypsin inhibitor. It was also observed that the in vitro protein digestibility of the developed cookies decreased as the level of substitution of the defatted-sesame seeds flour increased. This decrease might be associated with the increasing presence of trypsin inhibitor in the defatted-sesame seeds flour containing crackers (Fig. 3) and it might also be as a result of non-enzymatic browning (Maillard) reactions involving the interaction between inherent proteins and the available sugar, leading to non-reversible formation of compounds causing a decrease in the availability of protein for digestion. Meanwhile, thermal cross linking of some of the proteins could also make them unavailable for digestion. Similar decrease in in vitro protein digestibility upon inclusion and increasing substitution of blanched pigeon pea in acha-blanched pigeon pea crackers has been reported by Olagunju et al. [6].

3.8 Sensory properties of crackers made from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

The mean sensory scores of the cracker samples are presented in Table 6. There were significant differences (P < 0.05) among the composite crackers and the wheat crackers in terms of appearance, aroma, crispiness, taste, and overall acceptability. The control wheat cracker had the best preference in all the sensory attributes and this might be due to the fact that the assessors are more familiar with whole wheat cracker than crackers made from other flour sources. The highest rating obtained for the appearance of the control wheat cracker could be attributed to its off-white colour

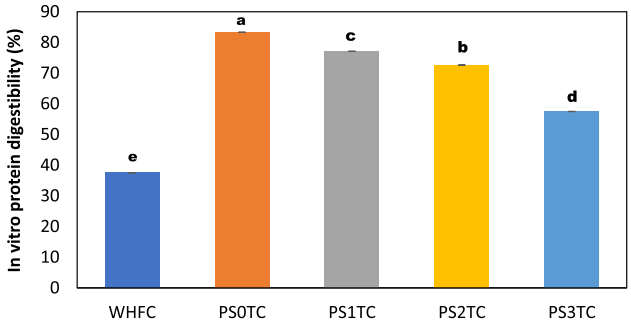


Fig. 4 In vitro protein digestibility of crackers made from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours. Error bars indicate standard deviation (N = 3). Charts with different alphabet are significantly different (P < 0.05). *WHFC* 100% Wheat flour cracker, *PS_0TC* 90% Pearl millet + 0% Sesame seed flour + 10% Tigernut flour cracker, *PS_1TC* 80% Pearl millet + 10% Sesame seed flour + 10% Tigernut flour cracker, *PS_2TC* 70% Pearl millet + 20% Sesame seed flour + 10% Tigernut flour cracker, *PS_3TC* 60% Pearl millet + 30% Sesame seed flour + 10% Tigernut flour cracker

compared to the developed crackers with slightly dark brown colour which might have given an impression that the products were over-baked. The browning of the developed crackers could be linked to caramelization of the sugars and Maillard reaction as the protein contributed by defatted-sesame seed might have reacted with sugar during the baking process. Similar observation has been reported by Alobo [41] for biscuits made from blends of millet and sesame seed flours. The nutty flavour of the added defatted-sesame seed flour could have contributed to the low appreciation of the aroma of the developed crackers compared to the control. The lower ratings and decrease in crispiness of the developed crackers upon increase in substitution level of defatted-sesame seed flour could be due to the absence of gluten which could have contributed to the strength of the crackers. The lower preference scores recorded for the taste of the developed cookies could be attributed to the change in ingredients and the perceived slight bitter after taste of the crackers. In a related study conducted by Meriles et al. [7], the low bitter aftertaste of crackers made from defatted chia flour, wheat germ, oat and quinoa was considered a positive attribute and it was attributed to excessive time/temperature baking conditions or by lipid oxidation. It is possible that some inherent compounds such as tannin in sesame seed flour may have negatively influenced the taste of the defatted-sesame flour containing crackers. No significant difference (P > 0.05) existed among the overall acceptability of the developed crackers. This could be attributed to the similar characteristics of the composite and wheat crackers in terms of appearance, aroma, crispiness and taste. Considering the average mean sensory score of above 6 obtained for the overall acceptability of the developed crackers, the developed crackers could be said to be generally acceptable by the panellists.

Table 6 Mean sensory scores of crackers from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours

Sample	Appearance	Aroma	Crispiness	Taste	Overall acceptability
WHFC	7.82 ± 1.23^{a}	7.24 ± 1.17^{a}	7.34 ± 1.42^{a}	8.02 ± 1.12^{a}	8.06 ± 1.19^{a}
PS_0TC	5.94 ± 1.96^{b}	6.24 ± 2.08^{b}	5.56 ± 2.23^{bc}	5.78 ± 2.12^{b}	6.28 ± 2.25^{b}
PS_1TC	5.88 ± 1.92^{b}	6.24 ± 1.67^{b}	5.92 ± 1.20^{b}	5.82 ± 2.10^{b}	6.38 ± 1.82^{b}
PS_2TC	5.58 ± 1.91^{b}	5.74 ± 1.59^{b}	5.88 ± 2.13^{b}	5.50 ± 2.15^{b}	6.50 ± 1.79^{b}
PS_3TC	5.56 ± 2.03^{b}	6.06 ± 1.62^{b}	4.88 ± 2.47^{c}	5.48 ± 2.41^{b}	6.34 ± 2.14^{b}

Values are means ± SD (n = 50); Means with different superscript along a column are significantly different (P < 0.05)

WHFC 100% Wheat flour cracker, *PS_0TC* 90% Pearl millet + 0% Sesame seed flour + 10% Tigernut flour cracker, *PS_1TC* 80% Pearl millet + 10% Sesame seed flour + 10% Tigernut flour cracker, *PS_2TC* 70% Pearl millet + 20% Sesame seed flour + 10% Tigernut flour cracker, *PS_3TC* 60% Pearl millet + 30% Sesame seed flour + 10% Tigernut flour cracker

4 Conclusion

Highly nutritious and functional gluten-free crackers were produced from germinated pearl millet, defatted-sesame seed and defatted-tigernut composite flours. Majority of the particles of the flours samples were retained on the sieve with mesh size of 90 µm. Functional properties of the composite flours as compared to wheat flour showed higher water and oil absorption capacities but lower loose and packed bulk densities. The developed crackers also demonstrated relatively darker colour as deduced from the objective colour (L^*) determination results and appearance of the crackers. Compared to the control wheat crackers, the developed crackers had lower weight, diameter and thickness but higher spread ratio. The moisture contents of the cracker samples were below the 10% recommended for long storage stability of food products. The nutritional compositions especially the ash, fibre, protein and energy contents of the developed crackers were superior to that of the wheat crackers, indicating the potential usefulness of the developed cookies in tackling protein-energy malnutrition. The phytate and trypsin inhibitor contents of the developed crackers were generally low and are not expected to be a source of concern to the bioavailability and absorption of the nutrients. The developed cookies showed higher calcium but relatively lower iron contents. The proteins of the developed crackers were highly digestible compared to that of the wheat cracker. Though the control had the highest sensory ratings, the developed crackers were generally accepted by the panellists. Among the developed gluten-free crackers, crackers produced from flour formulation comprising 70% germinated pearl millet, 10% defatted-tigernut and 20% defatted-sesame seed flours had the highest average overall acceptability value (6.50) while those made from 80% germinated pearl millet, 10% defatted-tigernut and 10% defatted-sesame seed flours had the highest average overall rating score (30.24). Production of crackers from pearl millet, sesame seed, and tigernut composite flours is recommended as an alternative to conventional wheat-based sweeter crackers. The use of this locally grown crops would not only enhance their utilization and minimise the adverse economic effect of wheat importation in low and non-wheat producing countries but would also contribute to food and nutrition security. Further research may explore the use of food-grade additives or ingredients' optimisation as a strategy to improve the sensory ratings of the developed crackers.

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Author contributions SAA and OAA conceptualized and designed the study. SAA, BOM and OAA carried out the laboratory work and developed the original draft of the manuscript. SAA, BOM, ROA, OA, WOJ and OAA were involved in data analysis, data interpretation and proofreading of the manuscript. All authors read and approved the final manuscript.

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Data availability The datasets generated during the current study are available from the corresponding authors upon reasonable request.

Declarations

Ethics approval and consent to participate The study was approved by the Ethical committee of the Department of Home Economics and Food Science, University of Ilorin, Nigeria after the presentation of the study proposal to the Departmental Research and Ethical committee. The assessors gave their informed consent to participate in the sensory evaluation of the novel gluten-free crackers in accordance with the IFST Guidelines for Ethical and Professional Practices for the Sensory Analysis of Foods [46]. All the panellists were regular consumers of crackers and their ability to discern variation in the organoleptic properties of snack foods was also tested.

Competing interests The authors declare that they have no competing interest.

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