Open Access

Recent Progress in Nutrition

LIDSEN Publishing Inc.

Original Research

Nutritional Enrichment and *In Vitro* Carbohydrate-Digesting Enzyme Inhibitory Potential of Yam-Tigernut Composite Doughmeals

Taiwo Ayodele Aderinola [1, *], Uche Capulet Anyaiwe [2], Blessing Oluwafemi Adeyemi [1]

1. Department of Food Science and Technology, Federal University of Technology, PMB 704, Akure, Nigeria; E-Mails: taaderinola@futa.edu.ng; oluwanifemia0@gmail.com
2. Department of Food Science and Technology, Delta State University of Technology, PMB 05, Ozoro, Nigeria; E-Mail: anyaiwecyriano@yahoo.com

* **Correspondence:** Taiwo Ayodele Aderinola; E-Mail: taaderinola@futa.edu.ng

Academic Editor: María Jose Esteve

Recent Progress in Nutrition
2026, volume 6, issue 3
doi:10.21926/rpn.2603022

Received: April 14, 2026
Accepted: September 13, 2026
Published: September 18, 2026

Abstract

Yam is a widely consumed staple food but has a high carbohydrate content and limited functional attributes. This study evaluated the nutritional, antioxidant, and *in vitro* antidiabetic properties of doughmeals produced from yam and tigernut flour blends at ratios of 95:5, 90:10, 85:15, 80:20, and 100% yam (control). Results showed that tigernut inclusion significantly improved the nutritional profile, with protein increasing from 8.09% to 11.81% and crude fiber rising from 0.24% to 1.14%. Ash and fat contents also increased notably, reflecting the mineral-dense and lipid-rich nature of tigernut. Phytochemical analysis revealed a substantial boost in total phenolic content, peaking at 14.07 mg GAE/g in the 20% blend compared with 6.56 mg GAE/g in the control. These compositional changes improved the functional and antioxidant potential of the doughmeals. Antioxidant capacity improved significantly across all assays, with hydroxyl radical scavenging nearly doubling (37.73% to 74.15%) and ABTS activity reaching 88.69%. Critically, the blends demonstrated significant *in vitro* inhibitory activity against key carbohydrate-digesting enzymes. Alpha-amylase inhibition rose from 43.74% to 80.61%, while alpha-glucosidase inhibition reached 72.56% in the fortified samples. Sensory evaluation confirmed that these improvements did not compromise consumer appeal, as overall acceptability remained statistically comparable to

the traditional control. The findings indicate that tigernut incorporation, up to 20%, enhanced the nutritional composition, antioxidant capacity, and *in vitro* carbohydrate-digesting enzyme inhibitory potential of the doughmeals.

Keywords
Functional foods; underutilized crops; tigernut; glycemic control; antioxidant capacity

1. Introduction

The global health landscape is currently faced with a staggering rise in the prevalence of non-communicable diseases (NCDs), with metabolic disorders, most notably type 2 diabetes and cardiovascular disease, leading the surge. Epidemiological projections suggest that the global prevalence of diabetes among adults aged 20-79 years will continue to increase significantly in the coming decades [1, 2]. This growth is particularly alarming in developing regions; currently, approximately 80% of individuals living with diabetes reside in low- and middle-income countries, where healthcare infrastructure often lacks the resources to manage chronic conditions effectively [3]. The 2019 global adult prevalence was reported at 9.3%, a figure that was further complicated by the COVID-19 pandemic, which saw a marked increase in mortality among diabetic patients due to compromised metabolic resilience [1, 4].

Diabetes mellitus is a chronic metabolic condition resulting in systemic hyperglycemia, driven by either insufficient insulin synthesis or a diminished cellular response to insulin action [3]. If left unmanaged, the chronic elevation of blood glucose leads to severe macrovascular and microvascular complications, including atherosclerosis, neuropathy, and renal failure. Dietary strategies that incorporate nutrient-dense foods and bioactive-rich plant materials have gained increasing attention as complementary approaches to support metabolic health and improving dietary quality. There is a burgeoning interest in the development of non-toxic, food-based interventions that leverage the natural bioactive compounds found in indigenous crops to influence carbohydrate digestion and potentially improve glycaemic responses [3, 5].

One crop that holds immense nutraceutical potential in this regard is the tigernut (*Cyperus esculentus*). Although many African regions consider it an underutilized tuber, it is a valuable nutrient source widely harvested in Nigeria, Spain, and Ghana. Tigernut is a nutrient-dense tuber containing appreciable amounts of carbohydrates, lipids, and proteins, including high-quality monounsaturated fats, starches, and proteins, alongside a robust micronutrient profile featuring vitamins C and E [6]. Its mineral composition is particularly noteworthy, showing high concentrations of phosphorus, potassium, and magnesium, which play vital roles in metabolic enzyme activation, bone density, and cardiovascular regulation [7, 8]. Furthermore, tigernut is a rich source of dietary fiber and resistant starch, which are essential for slowing glucose absorption, aiding in weight management, and supporting gut health [7, 8].

In West Africa, doughmeals (often referred to as “swallow”) are a dietary staple, frequently prepared from starchy roots and tubers like yam (*Dioscorea spp.*) [9, 10]. While yam provides essential carbohydrates and some B-vitamins, it often possesses a high glycemic index, which can trigger rapid postprandial blood glucose spikes, a significant risk factor for diabetic patients [11, 12].

Modifying traditional yam-based meals by incorporating nutrient-dense tubers like tigernut offers a promising strategy to balance the macronutrient profile and increase the diet's antioxidant density. Tigernut starch exhibits distinctive physicochemical properties that may influence food texture and functionality, providing a functional matrix that may improve the textural and nutritional quality of doughmeals [13, 14].

Contemporary trends in functional food product development are moving toward rational formulation design to engineer foods that offer specific metabolic benefits beyond basic nutrition [15-18]. The strategy involves creating a synergistic relationship between the bioactive components of plant-derived foods such as tigernut and the starch structure of yam. By manipulating the food matrix, specifically by increasing the fiber and lipid content, the accessibility of starch to digestive enzymes is reduced. This matrix-driven modification of the food structure may influence carbohydrate digestion by inhibiting key enzymes such as α-amylase and α-glucosidase, thereby contributing to potential improvements in postprandial glycaemic responses [19].

However, to support the development of nutritionally enhanced functional food products, comprehensive empirical data are urgently needed on the proximate and mineral compositions, as well as the antioxidant activity of these composite blends. Understanding the interaction between these ingredients is crucial for designing meals that maintain sensory appeal while enhancing nutritional and bioactive attributes. Previous studies have explored the incorporation of tigernut into food products because of its nutritional density and potential functional attributes. However, investigations into incorporating tigernut into traditional yam-based doughmeals remain limited, particularly regarding the combined evaluation of nutritional composition, antioxidant properties, carbohydrate-digesting enzyme inhibitory activity, and sensory acceptability [20-24]. Therefore, this study aimed to evaluate the proximate composition, mineral content, antioxidant activity, and *in vitro* enzyme-inhibitory properties of yam-tigernut composite doughmeal formulations, providing insights into their nutritional and bioactive potential as a functional food product.

2. Material and Methods

Tigernut was sourced from Shasha Market, and yam tubers were purchased from a vendor near the School of Agriculture and Agricultural Technology (SAAT), in Akure, Ondo State. All reagents used were of analytical grade.

2.1 Sample Preparation

2.1.1 Preparation of Tigernut Flour

Fresh tigernuts were sorted to remove extraneous materials such as stones, pebbles, and foreign seeds, then washed with tap water. The cleaned nuts were dried in a cabinet dryer at 60°C for 24 h until the moisture content reached approximately 13%. The dried nuts were milled (Euro Premium Jade EP-04, China) and sieved using a 600 µm mesh. The resulting flour was packed and sealed in polythene bags until analysis.

2.1.2 Preparation of Yam Flour

The yam tuber was washed, peeled, and sliced into water containing 1% sodium metabisulphite. The slices were then dried in a hot air oven at 65°C for 24 h and subsequently milled using an attrition mill.

2.1.3 Formulation of Blends

Tigernut and yam composite flours were blended in varying ratios (100:0, 95:5, 90:10, 85:15, 80:20), with 100% yam flour serving as the control. The Jade mixer above was used to mix the samples at speed 6 for 5 min to ensure uniform blending.

2.1.4 Preparation of Doughmeal

200 g of the yam and tigernut composite flour was added to 500 mL of boiling water and stirred continuously until a dough was formed. An additional 200 mL of water was then added, and the dough was cooked for 2 min before the final stirring and packaging.

2.2 Methods

2.2.1 Determination of the Proximate Composition

The following proximate compositions were determined following official methods [25]. Carbohydrate content was determined by difference.

Determination of Moisture Content. Ten grams of the sample were placed in pre-weighed dishes and dried in a hot air oven at 130 ± 1°C until a constant weight was achieved. The dishes were then transferred to a desiccator to cool to room temperature before reweighing. Moisture content (%) was calculated based on the weight loss.

Moisture content was calculated as:

$$MC(\%) = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

Where:
W_1 = weight of empty dish (g)
W_2 = weight of dish + sample before drying (g)
W_3 = weight of dish + dried sample (g)

Determination of Crude Fiber Content. Approximately 1 g of the sample was weighed into a conical flask (W_1) and boiled with 150 mL of 1.25% H_2SO_4 for 30 min. The mixture was filtered through a poplin cloth and rinsed with distilled water. The residue was returned to the flask and boiled with 150 mL of 1.25% NaOH for another 30 min. It was then filtered and rinsed sequentially with distilled water, 10% HCl, and ethanol. The final residue was scraped into a crucible, oven-dried, cooled in a desiccator, and weighed (W_2). It was then ashed in a muffle furnace, cooled again in a desiccator, and reweighed (W_3).

$$\%Crude\ fibre = \frac{W_2 - W_3}{W_1} \times 100$$

Where:
W_1 = weight of sample
W_2 = weight after oven drying
W_3 = weight after removal from furnace

Determination of Crude Protein Content. Crude protein determination involved three main steps: digestion, distillation, and titration. About 0.5 g of the sample was weighed into a 500 mL Kjeldahl flask, followed by the addition of a selenium catalyst and 10 mL of concentrated H_2SO_4. The mixture was digested at 400°C using a protein digester until a clear solution was formed, cooled, and diluted to 50 mL with distilled water. For distillation, 5 mL of 2% boric acid and two drops of a mixed indicator (bromocresol green and methyl red in alcohol) were added to a receiving flask, with the condenser tip submerged below the surface. Then, 5 mL of the digest and 10 mL of 40% NaOH were introduced into the distillation unit, and 50 mL of distillate was collected. The distillate was titrated the distillate with 0.1 M HCl until a pink endpoint is reached to determine the nitrogen content for crude protein calculation.

$$\%Nitrogen = \frac{Titre\ value \times 0.1\ M\ HCl \times 0.014 \times V_1V_2}{Weight\ of\ sample} \times 100$$

Where:
V_1 = volume of digest (50 mL)
V_2 = volume of digest used (5 mL)
%Crude protein = %Nitrogen × 6.25

Determination of Total Ash. Clean, dry crucibles were initially weighed and recorded as W_1. Approximately 0.5 g of each sample was added to the crucibles, which were then reweighed to obtain W_2. The crucibles and their contents were placed in a muffle furnace at 600°C and heated until a light grey ash was observed. After ashing, the crucibles were removed, allowed to cool to room temperature, and reweighed to obtain W_3. Ash content was calculated as:

$$\%Ash = \frac{W_3 - W_1}{W_2 - W_1} \times 100$$

Where:
W_1 = weight of empty crucible (g)
W_2 = weight of crucible + sample before ashing (g)
W_3 = weight of crucible + ash after ashing (g)

Determination of Crude Fat Content. Crude fat content was determined using the Soxhlet extraction method. Approximately 5.0 g of each flour sample was weighed into a cellulose extraction thimble and extracted with n-hexane in a Soxhlet apparatus for 3.5 h. The extraction flask was pre-weighed before adding the solvent. At the end of the extraction, the solvent was evaporated, and

the flask containing the extracted fat was dried to remove residual solvent, cooled in a desiccator, and reweighed. The crude fat content was calculated as:

$$\%Crude\ fat = \frac{W_2 - W_1}{W_s} \times 100$$

Where:
W_1 = weight of the empty extraction flask (g)
W_2 = weight of the flask plus extracted fat (g)
W_s = weight of the sample (g)

2.2.2 Determination of Mineral Composition

Mineral element concentrations in the samples were determined using flame atomic absorption spectrometry (FAAS). The samples were first dry-ashed to remove organic matter, and the resulting ash was dissolved in dilute acid. The prepared solution was then introduced into the flame atomic spectrophotometer (PYE Unicam SP9, UK), where calcium (Ca), magnesium (Mg), iron (Fe), and zinc (Zn) were quantified at their respective wavelengths. Sodium (Na) and potassium (K) were determined using a flame photometer, while phosphorus (P) was determined colorimetrically using the molybdovanadate method according to AOAC [25].

2.2.3 Extraction of Sample

The bioactive compounds were extracted following a modified method described by Aderinola and Mayomi [26]. Briefly, 1 g of each dried doughmeal sample was mixed with 10 mL of 80% methanol and shaken at room temperature for 2 h. The mixture was then centrifuged at 3000 × g for 10 min (Model KX3400C; KENXIN Intl. Co.), and the supernatant was collected. The resulting extract was filtered using Whatman No. 1 filter paper and stored at 4°C until further analysis. The extracts were used to determine total phenolic content, flavonoid content, antioxidant activity, and enzyme inhibition assays.

2.2.4 Determination of Total Flavonoid Content

The total flavonoid content of the samples' extract was determined using the colorimetric method [26]. Briefly, 0.2 mL of the extract was mixed with 0.3 mL of 5% $NaNO_3$ at time zero. After 5 min, 0.6 mL of 10% $AlCl_3$ was added, followed by the addition of 2 mL of 1 M NaOH after another 6 min. Finally, 2.1 mL of distilled water was added to the mixture. The absorbance was measured at 510 nm with Healicom 721S (China) UV-spectrophotometer against a reagent blank, and the total flavonoid content was expressed as milligrams of rutin equivalent (mg RE).

2.2.5 Determination of Total Phenol Content

The total phenol content of the samples' extract was determined using a previously reported method [26]. A volume of 0.2 mL of the extract was mixed with 0.5 mL of 10% Folin-Ciocalteu's reagent and 2 mL of 7.5% sodium carbonate. The mixture was incubated at 45°C for 40 min, after which the absorbance was measured at 700 nm using a spectrophotometer (Healicom 721S, China).

Gallic acid was used as the standard for phenol quantification, and results were expressed as mg gallic acid equivalents (mg GAE)/g.

2.2.6 Determination of 1,1-Diphenyl-2-Picrylhydrazyl (DPPH) Free Radical Scavenging Ability

The free radical scavenging ability of the extract was determined as previously reported [26]. Briefly, 1 mL of the extract was mixed with 1 mL of 0.4 mM methanolic DPPH solution. The mixture was kept in the dark for 30 min, after which the absorbance was measured at 516 nm with a Healicom 721S (China) UV spectrophotometer. The percentage inhibition of DPPH was calculated using the formula:

$$\%DPPH = \frac{A_{control} - A_{sample}}{A_{control}} \times 100$$

2.2.7 Determination of 2,2'-Azino-Bis (3-Ethylbenzothiazoline-6-Sulfonic Acid) (ABTS)

ABTS radicals were generated by reacting a 7 mM ABTS aqueous solution with 2.45 mM potassium persulfate ($K_2S_2O_8$) and allowing the mixture to stand in the dark for 16 h [26]. The resulting solution was diluted with ethanol to an absorbance of 0.700 at 734 nm. Then, 0.2 mL of the appropriately diluted extract was added to 2.0 mL of the ABTS solution, and the absorbance was measured at 734 nm after 15 min with a Healicom 721S (China) UV-spectrophotometer. ABTS radical scavenging ability of the samples was calculated using:

$$ABTS\ radical\ scavenging\ ability(\%) = \frac{A_{control} - A_{sample}}{A_{control}} \times 100$$

2.2.8 Determination of Ferric Reducing Property

The ferric reducing power of the samples was determined using a modification of a previously described method [26]. The sample was dissolved in a 0.2 M phosphate buffer which was maintained at pH 6.6. An aliquot of 250 µL was taken, and it was mixed with 250 µL of the buffer and 250 µL of 1% potassium ferricyanide solution. The mixture was thoroughly mixed using a vortex mixer, then heated at 50°C for 20 min. During incubation, 250 µL of 10% trichloroacetic acid (TCA) and 50 µL of 0.1% ferric chloride dissolved in double-distilled water were added. Then 200 µL of distilled water was also added. The solution was allowed to stand for 10 min at room temperature, then centrifuged at 1000 × g for 10 min. An aliquot (200 µL) of the supernatant was transferred to a clear-bottom 96-well plate, and absorbance was measured at 700 nm using a HealiCom 721S (China) UV spectrophotometer.

2.2.9 Determination of Hydroxyl Radical Scavenging Ability

The hydroxyl radical scavenging ability of the extract was determined following the previously described method [27]. Freshly prepared extract (0-100 µL) was added to a reaction mixture containing 120 µL of 20 mM deoxyribose, 400 µL of 0.1 M phosphate buffer (pH 7.4), 40 µL of 20 mM hydrogen peroxide, and 40 µL of 500 µM $FeSO_4$. The volume was adjusted to 800 µL with distilled water. The mixture was incubated at 37°C for 30 min, then stopped by adding 0.5 mL of 2.8% trichloroacetic acid (TCA), followed by 0.4 mL of 0.6% thiobarbituric acid (TBA) solution. The tubes

were then incubated in boiling water for 20 min, and absorbance was measured at 532 nm with a Healicom 721S (China) UV spectrophotometer. The percentage hydroxyl radical scavenging activity was calculated using the formula:

$$Hydroxyl\ radical\ scavenging\ ability(\%) = \frac{A_{control} - A_{sample}}{A_{control}} \times 100$$

2.2.10 Determination of α-Glucosidase Inhibitory Ability

The substrate, p-nitrophenyl-α-D-glucopyranoside (pNPG), was prepared in 20 mM phosphate buffer (pH 6.9). A volume of 100 µL of α-glucosidase (0.3 U/mL) was pre-incubated with 50 µL of the extract for 10 min. Then, 50 µL of 3.0 mM pNPG was added to initiate the reaction. The mixture was incubated at 37°C for 20 min, and the reaction was stopped by adding 2 mL of 0.1 M Na_2CO_3 [28]. The release of p-nitrophenol was measured at 405 nm with a Healicom 721S (China) UV spectrophotometer to determine enzyme activity. The percentage inhibition was calculated using the formula:

$$Alpha\ glucosidase\ inhibition(\%) = \frac{A_{control} - A_{sample}}{A_{control}} \times 100$$

2.2.11 Determination of α-Amylase Inhibitory Activity

A volume of 0.2 mL of the sample extract was mixed with 0.2 mL of the prepared α-amylase enzyme solution and incubated at 25°C for 3 min. Subsequently, 0.2 mL of substrate was added, and the mixture was further incubated under the same conditions. After incubation, 1 mL of 3,5-dinitrosalicylic acid (DNSA) reagent was added, and the mixture was heated in a boiling water bath (100°C) for 5 min. The mixture was then cooled, diluted with 10 mL of distilled water, and the absorbance was measured at 540 nm with a Healicom 721S (China) UV spectrophotometer against a blank containing buffer without enzyme [28]. The percentage inhibition of α-amylase activity was calculated using the formula:

$$Alpha\ amylase\ inhibition(\%) = \frac{A_{control} - A_{sample}}{A_{control}} \times 100$$

2.2.12 Sensory Evaluation

Twenty untrained panelists comprising students and staff of the Department of Food Science and Technology were recruited to evaluate the doughmeal samples prepared from each flour blend. The samples were presented in coded white plastic plates, and their order of presentation was randomized. Portable water was provided to the panelists to rinse their mouths between sample evaluations. Panelists evaluated the samples based on appearance, texture, aroma, and overall acceptability. Each attribute was rated using a 9-point Hedonic scale, where 1 = dislike extremely and 9 = like extremely.

2.3 Statistical Analysis

All chemical analyses were conducted in triplicate as technical replicates, and the results were expressed as mean values ± standard deviation (SD). Mean comparisons were performed using analysis of variance (ANOVA), and differences between means were separated using the least significant difference (LSD) test at a significance level of $p < 0.05$. Data were analyzed using SPSS version 21.

2.4 Ethical Statement/Informed Consent

This study adhered to the Declaration of Helsinki. Although ethics committee approval was not required for questionnaire studies on food-related consumer preferences and more so that no personal information (name, age, sex, etc.) was collected. This study uses exclusively anonymous questionnaires, ensuring that no participant data can be identified or linked to individual participants. Informed consent was obtained from the participants after they were properly informed about the study, including the approximate time required to complete the exercise. They were also told that they could withdraw from the study at any point without providing reasons and without facing any consequences.

3. Result and Discussion

3.1 Proximate Composition of Yam-Tigernut Doughmeal

Table 1 details the proximate profiles of the yam-tigernut doughmeal samples. Moisture content (MC) showed no significant difference ($p > 0.05$) across the various blends, with values ranging from 66.86% in Sample E (20% tigernut) to 68.68% in the 100% yam control (Sample A). This suggests that replacing yam flour with tigernut flour did not significantly influence the water retention capacity of the doughmeal. Maintaining moisture content within this range is important because excessive moisture may accelerate microbial growth and chemical deterioration during storage [29]. Ash content, which shows the total mineral levels [29], increased significantly as more tigernut was added, reaching its highest value of 1.19% in Sample B. Even though these figures are lower than what was found in water yam mixed with distiller's spent grain [30], the clear increase shows that tigernut is a good source of minerals [8]. Similarly, crude fiber rose from 0.15% in Sample C to 1.89% in Sample D. This increase may be attributed to the relatively high content of non-starch polysaccharides present in tigernut [7, 8]. Increased dietary fiber content is associated with improved nutritional quality and glycemic regulation since it can delay starch digestion and help manage blood sugar levels [5].

Table 1 Proximate Composition of yam-tigernut doughmeal (%).

Samples	MC	Ash	Fibre	Protein	Fat	CHO
A	68.68 ± 0.07^{a}	0.19 ± 0.04^{d}	0.24 ± 0.00^{b}	8.09 ± 0.03^{d}	6.87 ± 0.18^{b}	15.93 ± 0.17^{b}
B	68.05 ± 1.12^{a}	1.19 ± 0.02^{a}	0.54 ± 0.03^{b}	9.34 ± 0.03^{b}	5.73 ± 0.22^{d}	15.15 ± 0.98^{b}
C	68.36 ± 0.66^{a}	0.59 ± 0.01^{b}	0.15 ± 0.01^{b}	6.38 ± 0.04^{e}	6.14 ± 0.17^{c}	18.38 ± 0.45^{a}
D	67.39 ± 0.78^{a}	0.40 ± 0.00^{c}	1.89 ± 0.86^{a}	8.97 ± 0.06^{c}	7.02 ± 0.01^{b}	14.33 ± 1.57^{b}
E	66.86 ± 0.18^{a}	0.38 ± 0.01^{c}	1.14 ± 0.03^{ab}	11.81 ± 0.12^{a}	7.79 ± 0.13^{a}	12.02 ± 0.41^{c}

Results are mean values of triplicate determination ± standard deviation. Values within the same column having different letters are significantly ($p < 0.05$) different.

A: 100% yam flour.

B: 95% yam flour, 5% tigernut flour.

C: 90% yam flour, 10% tigernut flour.

D: 85% yam flour, 15% tigernut flour.

E: 80% yam flour, 20% tigernut flour.

MC: Moisture content.

CHO: Carbohydrate.

Although tigernut fortification generally increased protein content, a slight reduction was observed at the 10% substitution level (Sample C). This variation may reflect the combined influence of inherent variability in the raw materials together with analytical variation commonly associated with proximate determinations. Despite these intermediate fluctuations, the 20% substitution produced the highest protein content, indicating an overall improvement with increasing tigernut incorporation. This increase suggests that tigernut fortification can enhance the protein content of traditional yam-based meals such as *amala*, which are typically characterized by high carbohydrate and low protein contents [29]. At the same time, fat content increased from 5.73% to 7.79% in Sample E, which is expected given that tigernut is naturally oily. On the other hand, carbohydrate (CHO) content did not follow a consistent trend. It increased to 18.38% in Sample B but then decreased to 12.02% in Sample D. This variation may be attributed to proportional increases in other components such as protein, fat, and fiber within the composite formulations, which may be beneficial for metabolic health because it transforms the high-carb meal into a better-balanced functional doughmeal that could help with long-term wellness [5, 31].

3.2 Mineral Content of the Yam-Tigernut Doughmeal

Table 2 presents the mineral profiles of the yam-tigernut doughmeal formulations. The data show clear shifts in mineral concentrations across the different blends, which generally mirror the ash content trends observed earlier. These variations highlight how mixing yam and tigernut flours can change the micronutrient density of the final doughmeal. Sodium levels showed a downward trend as more tigernut was added, dropping from 1.84 mg/100 g in the control (Sample A) to 1.29 mg/100 g in Sample D. This reduction is a positive nutritional finding, especially for people managing hypertension or trying to lower their salt intake. While sodium is essential, the high potassium-to-sodium ratio often found in plant-based composites is a key factor in supporting cardiovascular health. Calcium content reached its highest level in Sample C (2.75 mg/100 g). This increase may be attributed to possible interactions between the mineral profiles of the two flour sources at the 90:10

substitution level, which seems to optimize the mineral balance in the matrix. Calcium is vital not just for bone structure but also for cell signaling and blood clotting [32].

Table 2 Mineral content of the yam tigernut doughmeal (mg/100 g).

Samples	**A**	**B**	**C**	**D**	**E**
Sodium	1.84 ± 0.01^{a}	1.47 ± 0.01^{c}	1.34 ± 0.01^{d}	1.29 ± 0.00^{e}	1.56 ± 0.01^{b}
Calcium	1.73 ± 0.01^{b}	0.53 ± 0.60^{c}	2.75 ± 0.01^{a}	1.38 ± 0.02^{b}	1.98 ± 0.02^{b}
Magnesium	0.81 ± 0.01^{c}	0.46 ± 0.00^{e}	1.33 ± 0.04^{a}	0.78 ± 0.02^{d}	0.95 ± 0.07^{b}
Iron	1.83 ± 0.00^{b}	1.53 ± 0.00^{c}	2.09 ± 0.00^{a}	1.33 ± 0.00^{d}	1.19 ± 0.00^{e}
Phosphorus	7.36 ± 0.56^{d}	10.26 ± 0.03^{b}	7.80 ± 0.01^{c}	5.86 ± 0.03^{e}	10.34 ± 0.03^{a}
Zinc	2.12 ± 0.00^{a}	1.58 ± 0.01^{d}	1.84 ± 0.01^{b}	1.63 ± 0.01^{c}	1.48 ± 0.00^{e}
Potassium	2.51 ± 0.01^{b}	2.57 ± 0.01^{a}	2.11 ± 0.01^{d}	2.08 ± 0.00^{d}	2.47 ± 0.01^{c}

Results are mean values of triplicate determinations ± standard deviation. Values within the same column having different letters are significantly ($p < 0.05$) different.

A: 100% yam flour.

B: 95% yam flour, 5% tigernut flour.

C: 90% yam flour, 10% tigernut flour.

D: 85% yam flour, 15% tigernut flour.

E: 80% yam flour, 20% tigernut flour.

Magnesium levels also changed significantly, with Sample C showing the highest concentration at 1.33 mg/100 g. This increase is particularly relevant when considering the metabolic goals of this study. Magnesium acts as a cofactor for over 300 enzymatic reactions, including those involved in glucose metabolism and insulin sensitivity [33, 34]. Given the potential of these blends to inhibit carbohydrate-digesting enzymes *in vitro*, the presence of adequate magnesium could be a contributing factor to how these doughmeals help regulate blood sugar levels. Iron content peaked in Sample C at 2.09 mg/100 g before declining in the samples with higher tigernut inclusion. This improvement in iron levels is noteworthy because iron deficiency remains a major global health concern, particularly in regions where tuber-based staples are common [35]. The higher iron in Sample C also aligns with the increased phenolic and flavonoid content observed in Figure 1. Research suggests that certain plant bioactive compounds can interact with minerals, sometimes forming complexes that influence their stability within the food matrix [8, 36, 37]. Phosphorus also increased substantially, particularly in Sample B (10.26 mg/100 g) and Sample E (10.34 mg/100 g). Tigernut is well-known for being rich in phosphorus, which works alongside calcium and magnesium to support bone mineralization and energy production in the form of ATP [8]. Although some minerals showed irregular patterns across the samples, the overall results suggest that replacing a portion of yam flour with tigernut generally improves the micronutrient profile. These shifts transform a simple starch-heavy meal into a more nutrient-dense functional food that supports broader metabolic health [31].

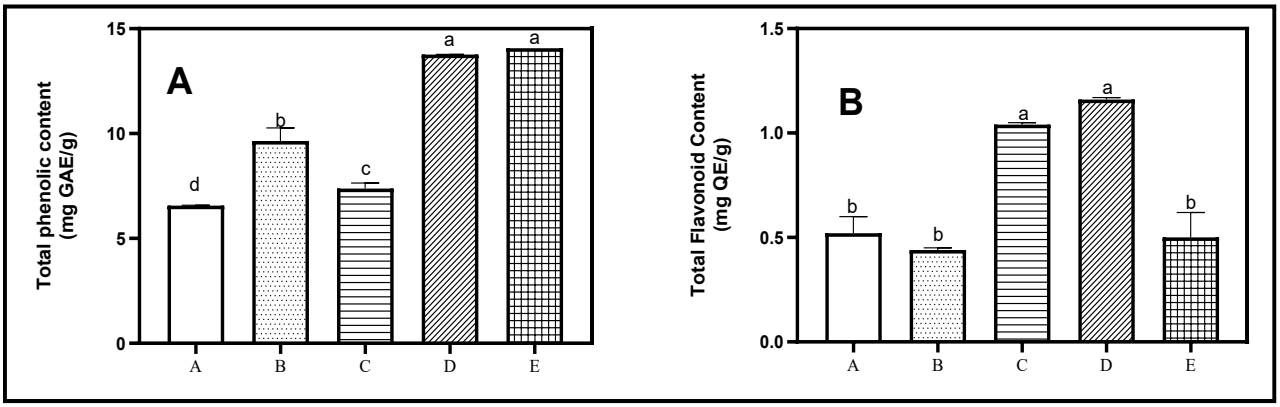

Figure 1 Total phenolic (A) and total flavonoid (B) contents of the yam-tigernut doughmeal. Bars with different letters are significantly different ($p < 0.05$). A: 100% yam flour. B: 95% yam flour, 5% tigernut flour. C: 90% yam flour, 10% tigernut flour. D: 85% yam flour, 15% tigernut flour. E: 80% yam flour, 20% tigernut flour.

3.3 Phytochemical Profiles of Yam-Tigernut Doughmeal

The total phenolic content (TPC) and total flavonoid content (TFC) of the doughmeal samples increased significantly as the level of tigernut substitution increased (Figure 1). TPC rose from 6.56 mg GAE/g in the pure yam control (Sample A) to 14.07 mg GAE/g in Sample E. It is noteworthy that Samples D and E showed the highest phenolic concentrations, which clearly indicates that *Cyperus esculentus* is an excellent source of bioactive compounds [38]. These phenolic compounds contribute significantly to the antioxidant potential of foods and may support dietary strategies to manage oxidative stress-related conditions. This increase in TPC also seems to follow the rise in protein and fiber seen in the proximate data, as these macronutrients can sometimes form a protective matrix that helps keep phenolic compounds stable during food processing. TFC followed a similar upward trend, reaching its highest level of 1.16 mg QE/g in Sample D (Figure 1B). Flavonoids are well-regarded for their health-promoting properties, including anti-inflammatory and vascular benefits [39]. Interestingly, while TPC continued to rise through Sample E, the flavonoid content showed a slight decrease in the 20% blend compared to the 15% blend. This might suggest a specific interaction within the food matrix or a dilution effect at higher substitution levels. Overall, enriching yam doughmeal with these phytochemicals significantly boosts its value as a functional food, moving it beyond a simple energy source to a meal with potential medicinal properties [8, 37].

3.4 Antioxidant and Phytochemical Properties of Yam-Tigernut Doughmeal

The observed increase in phenolic and flavonoid contents following tigernut incorporation is consistent with previous reports describing tigernut as a source of bioactive compounds [7, 8, 39-41]. However, variations among studies may arise from differences in cultivar, processing conditions, and extraction methods. The enrichment of these phytochemicals may contribute to the improved antioxidant activity observed in the fortified doughmeals, as phenolic compounds and flavonoids are effective hydrogen donors and metal chelators that can neutralise reactive oxygen species. In addition, the increased mineral content, particularly magnesium, iron, and phosphorus, may indirectly contribute to antioxidant potential by supporting endogenous antioxidant defence mechanisms and cellular metabolic functions. Therefore, the enhanced antioxidant activity of the

tigernut-fortified doughmeals likely results from the combined effects of increased phytochemical content and improved nutritional composition rather than from a single component alone. The ability of the doughmeal to neutralize free radicals was assessed using multiple assays, including hydroxyl radical scavenging, ABTS, DPPH, and ferric reducing antioxidant power (FRAP). Across all measures, adding tigernut flour significantly increased antioxidant capacity (Figure 2). Hydroxyl radical scavenging activity, which is a key indicator of how well a food can protect cells from oxidative damage, nearly doubled from 37.73% in the control to 74.15% in Sample E (Figure 2A). This sharp increase is likely due to the high concentration of polyphenols found in tigernut, which are known for their effective radical-scavenging mechanisms [8, 37]. Similarly, both ABTS and DPPH scavenging activities improved markedly. ABTS values rose from 54.84% to 88.69%, while DPPH activity increased from 20.84% to 43.03% (Figures 2B, 2C). The fact that the doughmeal performed well in both assays is important because it shows the formulations can neutralize different types of free radicals-those that are water-soluble and those that are more lipid-soluble. This broad-spectrum antioxidant protection is a hallmark of high-quality functional foods. The steady increase in DPPH scavenging activity may also be associated with the higher lipid fraction of tigernut, which can contain lipid-soluble antioxidant compounds [19].

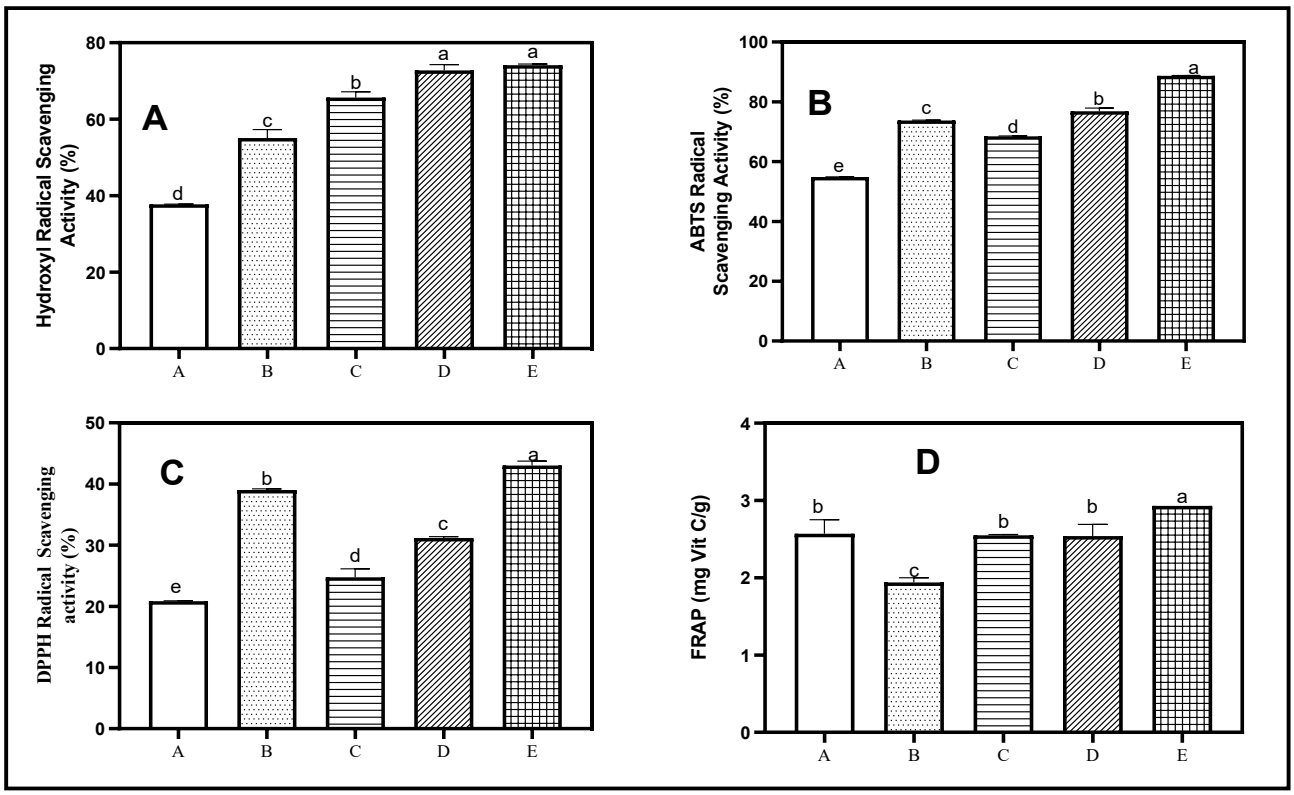

Figure 2 Antioxidant properties of yam-tigernut doughmeal. Bars with different letters are significantly different ($p < 0.05$). A: 100% yam flour. B: 95% yam flour, 5% tigernut flour. C: 90% yam flour, 10% tigernut flour. D: 85% yam flour, 15% tigernut flour. E: 80% yam flour, 20% tigernut flour.

The FRAP assay, which measures the ability of the sample to reduce ferric ions (Fe^{3+}) to ferrous ions (Fe^{2+}), also showed an upward trend, moving from 2.57 to 2.93 mg Vit C/g (Figure 2D). This indicates that the bioactive compounds in the yam-tigernut blends are not just good at scavenging

radicals but are also act as electron donors, another way they help prevent oxidative stress. These results are particularly meaningful when linked to the *in vitro* inhibitory activity against carbohydrate-digesting enzymes discussed in later sections (Figure 3). Since oxidative stress is a major driver of complications in metabolic diseases, a doughmeal that provides such strong antioxidant defenses could benifit individuals managing blood sugar issues [5, 42]. By combining the energy of yam with the protective antioxidants of tigernut, these blends offer a promising dietary strategy for improving long-term metabolic health.

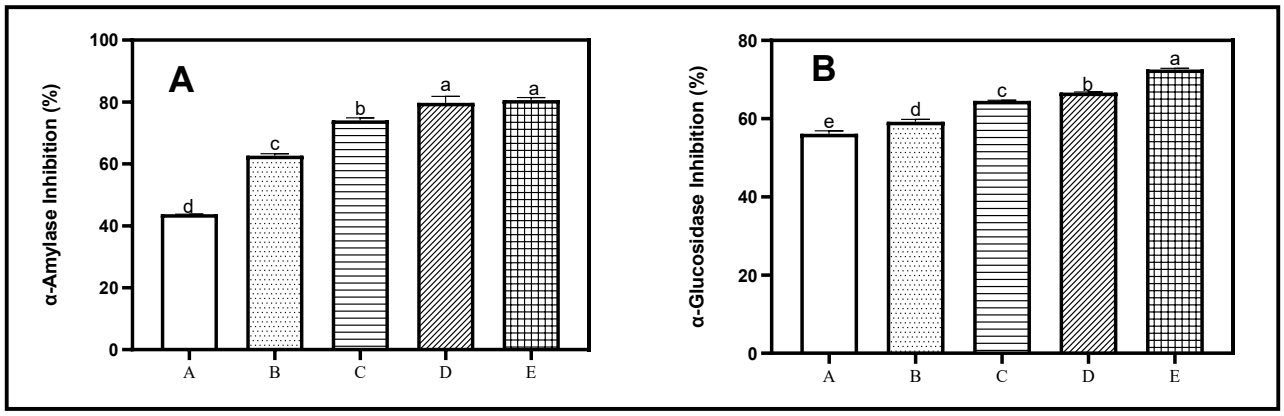

Figure 3 α-Amylase (A) and α-Glucosidase (B) inhibitory potential of the doughmeal. Bars with the different letters are significantly ($p < 0.05$) different. A: 100% yam flour. B: 95% yam flour, 5% tigernut flour. C: 90% yam flour, 10% tigernut flour. D: 85% yam flour, 15% tigernut flour. E: 80% yam flour, 20% tigernut flour.

3.5 In Vitro Antidiabetic Properties of Yam-Tigernut Doughmeal

The results for the α-amylase and α-glucosidase inhibitory activities are illustrated in Figure 3. The data reveal a clear *in vitro* inhibitory activity against carbohydrate-digesting enzymes of the doughmeal as the proportion of tigernut flour increased. Specifically, α-amylase inhibition rose from 43.74% in the pure yam control (Sample A) to 80.61% in Sample E (Figure 3A). This is a vital finding because α-amylase breaks down complex starches into smaller oligosaccharides. By inhibiting this enzyme, the doughmeal can effectively slow down the rate at which starch is converted into sugar, which helps prevent the sharp spikes in blood glucose that often occur after a meal [42]. This trend aligns with recent studies on composite flours, which suggest that underutilized crops can significantly alter the digestive kinetics of plant-based staples [15, 16, 31]. Similarly, α-glucosidase inhibition increased from 56.12% in the control to 72.56% in the 20% tigernut blend (Figure 3B). While α-amylase starts the digestion process, α-glucosidase is responsible for the final step of breaking down disaccharides into glucose in the small intestine. The ability of these formulations to suppress both enzymes suggests a dual-action mechanism that not only delays the start of starch breakdown but also limits the final absorption of glucose into the bloodstream. These results are particularly promising for developing functional foods tailored for individuals managing type 2 diabetes or those in prediabetic states [5].

The enhanced inhibitory effects observed in this study can be linked to the chemical changes in the dough matrix. The significant increase in crude fiber, fat, and specific phytochemicals, namely total phenolics and flavonoids (Figure 1), plays a major role in these results. Phenolic compounds

are known to interact with the active sites of digestive enzymes, thereby reducing their catalytic efficiency in carbohydrate hydrolysis [31]. Furthermore, the high fiber content likely creates a physical barrier that traps starch granules, making them less accessible to enzymes. When combined with the strong antioxidant activities reported in Figure 2, it is clear that these yam-tigernut blends do more than just provide energy; they offer a protective effect that may contribute to improved metabolic responses through antioxidant and enzyme inhibitory mechanisms [5, 43]. This makes the 15% and 20% tigernut substitutions (Samples D and E) particularly effective candidates for health-focused dietary interventions.

3.6 Sensory Evaluation of Yam-Tigernut Doughmeal

Table 3 presents the sensory assessment results for the doughmeal samples. A critical finding in this study is that, although the control (Sample A) received the highest numerical mean scores across most parameters, there were no significant differences in overall acceptability between the 100% yam doughmeal and the tigernut-fortified blends. The improved nutritional profile together with comparable sensory acceptability suggests that the formulated doughmeals achieved the intended balance between nutritional enhancement and consumer acceptance. Appearance scores trended a downward, from 7.48 in Sample A to 6.68 in Sample E. This slight decline likely stems from the darker pigmentation and visible fiber particles introduced by the tigernut flour, which alter the expected uniform color of the traditional yam meal. However, even at 20% substitution, the score remained well within the acceptable range. In contrast, the aroma scores actually improved as tigernut inclusion increased, peaking at 7.37 in Sample E. This improvement is likely due to the release of pleasant, nutty volatile compounds during the preparation of the dough, which are characteristic of *Cyperus esculentus* [39]. Texture ratings showed that there was no significant ($p > 0.05$) difference across all formulations, moving only slightly from 7.28 to 6.85. This suggests that the additional fat and fiber from tigernut (Table 1) did not adversely affect the textural quality attributes usually associated with yam-based swallows.

Table 3 Quality acceptability of yam-tigernut doughmeal.

Samples	Appearance	Texture	Aroma	Overall Acceptability
A	7.48 ± 0.96^{a}	7.28 ± 1.11^{a}	7.13 ± 1.18^{ab}	7.55 ± 1.11^{a}
B	7.33 ± 0.86^{a}	7.00 ± 1.09^{a}	6.73 ± 1.11^{b}	7.23 ± 1.07^{a}
C	7.18 ± 0.84^{a}	7.10 ± 1.01^{a}	6.93 ± 1.23^{ab}	7.30 ± 0.99^{a}
D	6.92 ± 0.94^{b}	6.90 ± 1.03^{a}	7.20 ± 0.91^{ab}	7.23 ± 0.95^{a}
E	6.68 ± 1.11^{b}	6.85 ± 1.22^{a}	7.37 ± 1.04^{a}	7.15 ± 1.03^{a}

Results are mean values of triplicate determinations ± standard deviation. Values within the same column having different letters are significantly ($p < 0.05$) different.

A: 100% yam flour.

B: 95% yam flour, 5% tigernut flour.

C: 90% yam flour, 10% tigernut flour.

D: 85% yam flour, 15% tigernut flour.

E: 80% yam flour, 20% tigernut flour.

The lipid fraction in tigernut may have acted as a lubricant, maintaining a smooth mouthfeel despite the reduction in total starch. The comparable texture across formulations may also relate to yam starch's ability to hydrate and gelatinise during doughmeal preparation. The presence of tigernut fibre and lipid components may influence the starch matrix by modifying water distribution and structural interactions, thereby preventing major changes in cohesiveness and handling characteristics. The overall acceptability scores, ranging from 7.55 to 7.15, demonstrate that samples remained acceptable to the panellists. While the control remains the sensory benchmark, the 20% substitution (Sample E) provides nearly double the protein and significantly higher antioxidant (Figure 2) and *in vitro* carbohydrate-digesting enzyme inhibitory potential (Figure 3) compared to the control. This balance between enhanced nutritional functionality and consumer acceptability suggests that these blends may serve as viable alternatives for improving the nutritional quality of traditional yam-based doughmeals without requiring a significant compromise on sensory attributes. Although sample C recorded the highest numerical overall acceptability score (7.30) among the fortified formulations, it did not differ significantly ($p > 0.05$) from the other blends.

4. Conclusion

In summary, this study demonstrated that substituting yam flour with tigernut flour is a promising approach for improving the nutritional quality of yam-based doughmeal. The integration of tigernut significantly boosted protein and crude fiber levels, addressing nutritional gaps typically found in tuber-based staples. Mineral analysis also showed a clear enrichment in essential micronutrients, particularly magnesium and iron, which are vital for overall metabolic health. From a therapeutic perspective, the increased inclusion of tigernut led to a significant improvement in antioxidant capacity and phytochemical content. These changes were directly linked to the doughmeal's ability to inhibit α-amylase and α-glucosidase activities. The findings suggest that these blends may slow starch digestion and reduce postprandial glucose responses, indicating potential usefulness in developing functional foods targeted at glycemic management. Moreover, while the pure yam control remained the sensory benchmark, the fortified blends, including the 20% substitution, showed no significant difference in overall consumer acceptability. Although Sample C recorded the highest numerical overall acceptability among the fortified formulations, this did not differ significantly ($p > 0.05$) from the other blends. This indicates that the substantial gains in metabolic and nutritional benefits do not require a compromise on the eating experience. The results indicate that a 20% tigernut substitution provided a favourable balance between nutritional enhancement and sensory acceptability, and is therefore recommended as the most favourable formulation among those evaluated in this study based on its superior nutritional composition, antioxidant activity, *in vitro* carbohydrate-digesting enzyme inhibitory activity, and comparable consumer acceptability. A limitation of this study is that the potential for glycaemic modulation was inferred from *in vitro* enzyme inhibitory activity and was not validated through in vivo studies or glycaemic index determination. Therefore, further studies are required to confirm the physiological relevance of these findings.

Author Contributions

Conceptualization: TAA; Formal analysis: BOA; Methodology: TAA, UCA, BOA; Project administration; Supervision: TAA; Writing-original draft: BOA; and Writing-review & editing: TAA, UCA. All authors reviewed the results and approved the final version of the manuscript.

Funding

No funding was received for this study.

Competing Interests

The authors have declared that no competing interests exist.

Data Availability Statement

Data is available from corresponding author on request.

AI-Assisted Technologies Statement

ChatGPT was used to improve grammar, readability, and clarity. All scientific content, analyses, and interpretations were developed independently by the authors, who reviewed the text and take full responsibility for the manuscript.

References

1. Sun H, Saeedi P, Karuranga S, Pinkepank M, Ogurtsova K, Duncan BB, et al. IDF Diabetes Atlas: Global, regional and country-level diabetes prevalence estimates for 2021 and projections for 2045. Diabetes Res Clin Pract. 2022; 183: 109119.
2. Ong KL, Stafford LK, McLaughlin SA, Boyko EJ, Vollset SE, Smith AE, et al. Global, regional, and national burden of diabetes from 1990 to 2021, with projections of prevalence to 2050: A systematic analysis for the global burden of disease study 2021. Lancet. 2023; 402: 203-234.
3. Oluwajuyitan TD, Ijarotimi OS. Nutritional, antioxidant, glycaemic index and antihyperglycaemic properties of improved traditional plantain-based (*Musa AAB*) dough meal enriched with tigernut (*Cyperus esculentus*) and defatted soybean (*Glycine max*) flour for diabetic patients. Heliyon. 2019; 5: e01504.
4. Xie Y, Al-Aly Z. Risks and burdens of incident diabetes in long COVID: A cohort study. Lancet Diabetes Endocrinol. 2022; 10: 311-321.
5. Zhao C, Yang C, Wai ST, Zhang Y, Portillo MP, Paoli P, et al. Regulation of glucose metabolism by bioactive phytochemicals for the management of type 2 diabetes mellitus. Crit Rev Food Sci Nutr. 2019; 59: 830-847.
6. Belewu MA, Belewu KY. Comparative physico-chemical evaluation of tiger-nut, soybean and coconut milk sources. Int J Agric Biol. 2007; 5: 785-787.
7. Maduka N, Ire FS. Tigernut plant and useful application of tigernut tubers (*Cyperus esculentus*)-A review. Curr J Appl Sci Technol. 2018; 29: 1-23.
8. Oluwakemi AA, Irewunmi AF, Joshua SK, Iweunor ND. Mineral, vitamin and phytochemical content of the tigernut. World J Appl Chem. 2021; 6: 36-40.

9. Mayomi PT, Aderinola TA. Proximate, mineral, amino acid composition, and bioactive properties of dough meals supplemented with African walnut flour. Food Sci Eng. 2024; 5: 404-417.
10. Bolade MK. Comparative evaluation of quality characteristics and acceptability of doughmeals from yam (*Dioscorea rotundata*), plantain (*Musa AAB*) and whole wheat grains (*Triticum spp.*). J Sustain Technol. 2017; 8: 93-106.
11. Senavirathna RM, Ekanayake S, Jansz ER, Welihinda J. Proximate composition, glycemic indices, and some factors affecting glycemic indices of underutilized tubers. Starch Stärke. 2014; 66: 1041-1048.
12. Ojo O, Ojo OO, Adebowale F, Wang XH. The effect of dietary glycaemic index on glycaemia in patients with type 2 diabetes: A systematic review and meta-analysis of randomized controlled trials. Nutrients. 2018; 10: 373.
13. Chukwuma ER, Obioma N, Christopher OI. The phytochemical composition and some biochemical effects of Nigerian tigernut (*Cyperus esculentus* L.) tuber. Pak J Nutr. 2010; 9: 709-715.
14. Djomdi, Hamadou B, Gibert O, Tran T, Delattre C, Pierre G, et al. Innovation in tigernut (*Cyperus esculentus* L.) milk production: In situ hydrolysis of starch. Polymers. 2020; 12: 1404.
15. Aderinola TA. Effects of processing techniques on the functional properties of wheatbreadfruit composite flour. Int Food Res J. 2016; 23: 2759-2762.
16. Aderinola T, Adeoye AD. Proximate, amino acid compositions and functional properties of maize-beans composite flours. Food Sci Eng. 2022; 4: 9-19.
17. Oloniyo RO, Omoba OS, Awolu OO. Rheological behaviour, physical and sensory properties of orange fleshed sweet potato and soy concentrate bread. J Food Sci Technol. 2022; 59: 2189-2199.
18. Akinyede AI, Ayibiowu EO, Fakologbon T, Awolu OO, Fagbemi TN. Nutritional assessment, glycemic indices and anti-diabetic potentials of dough meal generated from optimized blends of matured plantain, soya cake and wheat bran flours. J Future Foods. 2023; 3: 374-382.
19. Badejo AA, Falarunu AJ, Duyilemi TI, Fasuhanmi OS. Antioxidative and anti-diabetic potentials of tigernut (*Cyperus esculentus*) sedge beverages fortified with *Vernonia amygdalina* and *Momordica charantia*. J Food Meas Charact. 2020; 14: 2790-2799.
20. Tazoho GM, Tchassi BB, Bossi DS, Tene ST, Womeni HM, Gouado I. Formulation of gluten-free biscuits based on tiger nut, Dana, and mixture of avocado and margarine: Nutritional composition and glycemic index of optimal sample. Food Sci Nutr. 2026; 14: e71852.
21. Obinna-Echem PC, Maurice IF, Fyne-Akah H, Barber LI. Quality assessment of pancakes produced from wheat and tigernut composite flour. Int J Food Sci Nutr. 2024; 9: 12-20.
22. Adebowale AA, Kareem ST, Sobukola OP, Adebisi MA, Obadina AO, Kajihausa OE, et al. Mineral and antinutrient content of high quality cassava-tigernut composite flour extruded snack. J Food Process Preserv. 2017; 41: e13125.
23. Adebayo-Oyetoro AO, Ogundipe OO, Lofinmakin FK, Akinwande FF, Aina DO, Adeyeye SA. Production and acceptability of chinchin snack made from wheat and tigernut (*Cyperus esculentus*) flour. Cogent Food Agric. 2017; 3: 1282185.
24. Aderinola TA, Kareem BR, Adewoye OO, Adeboye A. Optimizing tigernut flour inclusion in wheat bread for enhanced nutritional, functional, and sensory quality. Food Mater Res. 2025; 5: e024.

25. AOAC International. Official methods of analysis of AOAC International. 19th ed. Gaithersburg, MD, USA: AOAC International; 2012.
26. Aderinola TA, Mayomi PT. Functional, nutritional and in-vitro antidiabetic properties of plantain-African walnut composite flour. Food Nutr. 2025; 1: 100001.
27. Halliwell B, Gutteridge JM. Formation of a thiobarbituric-acid-reactive substance from deoxyribose in the presence of iron salts: The role of superoxide and hydroxyl radicals. FEBS Lett. 1981; 128: 347-352.
28. Kim JS, Hyun TK, Kim MJ. The inhibitory effects of ethanol extracts from sorghum, foxtail millet and proso millet on α-glucosidase and α-amylase activities. Food Chem. 2011; 124: 1647-1651.
29. Idowu MA, Adeola AA, Olaniyan DJ, Oke EK, Omoniyi SA. Quality evaluation of cocoyam-cowpea flour blends and sensory attributes of their cooked paste (*Amala*). Ann Food Sci Technol. 2017; 18: 183-191.
30. Awoyale W, Maziya-Dixon B, Sanni LO, Shittu TA. Effect of water yam (*Dioscorea alata*) flour fortified with distiller's spent grain on nutritional, chemical, and functional properties. Food Sci Nutr. 2016; 4: 24-33.
31. Olugbuyi AO, Oladipo GO, Malomo SA, Ijarotimi SO, Fagbemi TN. Biochemical ameliorating potential of optimized dough meal from plantain (*Musa AAB*), soycake (*Glycine max*) and rice bran (*Oryza sativa*) flour blends in streptozotocin induced diabetic rats. Appl Food Res. 2022; 2: 100097.
32. Achoribo ES, Ong MT. Tiger nut (*Cyperus esculentus*): Source of natural anticancer drug? Brief review of existing literature. Euro Mediterr Biomed J. 2017; 12: 91-94.
33. Dastgerdi AH, Rad MG, Soltani N. The therapeutic effects of magnesium in insulin secretion and insulin resistance. Adv Biomed Res. 2022; 11: 54.
34. Veronese N, Dominguez LJ, Pizzol D, Demurtas J, Smith L, Barbagallo M. Oral magnesium supplementation for treating glucose metabolism parameters in people with or at risk of diabetes: A systematic review and meta-analysis of double-blind randomized controlled trials. Nutrients. 2021; 13: 4074.
35. Famakin O, Fatoyinbo A, Ijarotimi OS, Badejo AA, Fagbemi TN. Assessment of nutritional quality, glycaemic index, antidiabetic and sensory properties of plantain (*Musa paradisiaca*)-based functional dough meals. J Food Sci Technol. 2016; 53: 3865-3875.
36. Ade-Omowaye BI, Akinwande BA, Bolarinwa IF, Adebiyi AO. Evaluation of tigernut (*Cyperus esculentus*) wheat composite flour and bread. Afr J Food Sci. 2008; 2: 87-91.
37. Adejuyitan JA. Tigernut processing: Its food uses and health benefits. Am J Food Technol. 2011; 6: 197-201.
38. Ihenetu SC, Ibe FC, Inyamah PC. Comparative study of the properties of yellow and brown *Cyperus esculentus* L. World News Nat Sci. 2021; 35: 25-37.
39. Abdullahi N, Badau MH, Umar NB, Yunusa AK, Rilwan A, Jibril H, et al. Tigernut: A nutrient-rich underutilized crop with many potentials. FUDMA J Sci. 2022; 6: 103-115.
40. Oladele AK, Liman AA, Abass MF, Ekawu B. Chemical, techno-functional, and antioxidant properties of tigernut (*Cyperus esculentus* L.) residue flours. Fed Univ Dutsinma J Agric Agric Technol. 2023; 9: 179-188.
41. Oladele AK, Adebowale JO, Bamidele OP. Phenolic profile and antioxidant activity of brown and yellow varieties of tigernut (*Cyperus esculentus* L.). Niger Food J. 2017; 35: 51-59.

42. Bungau SG, Vesa CM, Bustea C, Purza AL, Tit DM, Brisc MC, et al. Antioxidant and hypoglycemic potential of essential oils in diabetes mellitus and its complications. Int J Mol Sci. 2023; 24: 16501.
43. Bhushan MS, Rao CH, Ojha SK, Vijayakumar M, Verma A. An analytical review of plants for anti diabetic activity with their phytoconstituent & mechanism of action. Int J Pharm Sci Res. 2010; 1: 29-46.