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Original Research Article

Nutritional Assessment of Doughnut Prepared from Red Potato Flour (*Solanum tuberosum l.*) Fortified with Bambara Nut Flour (*Vigna subterranean l.*)

Godfrey Okechukwu Eneogwe[1]*, Ejike Onwudiegwu Okpala[1], William Ojoniko Anthony[1], Esther Izihyi Ibrahim[2], Anthony Ugbedeojo Atumeyi[1], Bilkisu idris Abdullahi[1], Faith Obuye[1], Prince Chukwudi Ossai[2]

[1]*Department of Chemistry, Federal University Lokoja, Kogi State, Nigeria*

[2]*Department of Industrial Chemistry, Federal University Lokoja, Kogi State, Nigeria*

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ABSTRACT

The proximate composition, mineral concentration, functional properties, and amino acid profile of flour blends from red potato and Bambara nut at 0%, 10%, 20%, 30%, and 40% were carried out. The codes used were: GOE (100% red potato flour and 0% Bambara nut flour), OEO (90% red potato flour and 10% Bambara nut flour), WAO (80% red potato flour and 20% Bambara nut flour), GWI (70% red potato flour 30% Bambara nut flour), and PCO (60% red potato flour and 40% Bambara nut flour). Doughnuts were prepared using these blends and their sensory properties were assessed. doughnuts with 20% Bambara nut flour (WOA) were the most acceptable among the samples. Furthermore, the results revealed that the protein content of the flour increased with an increase in Bambara nut flour addition. Significant differences ($p \le 0.05$) were observed in the ash, moisture, fat, crude fibre, and carbohydrate (1.94±0.50-3.23±0.05 %, 8.74±1.01-18.90±0.76 %, 6.70±0.41-13.46±0.12 %, 5.00±0.42-21.06±0.16 %, and 30.18±0.28-50.69±0.41%), respectively. The mineral concentration of the flour samples also showed an increase as the fortification increased. Other than the gelatinization temperature which showed a decrease, other functional properties analysed showed an increase with enrichment. The samples were also rich in amino acids. However, PCO was the richest in amino acid content, as it had 44.47±0.06 g/100g and 53.10 ±0.02 g/100g, for essential and non-essential amino acids respectively. The findings of this study revealed that there was an improvement in the nutritional composition of the flour sample as the Bambara nut flour.

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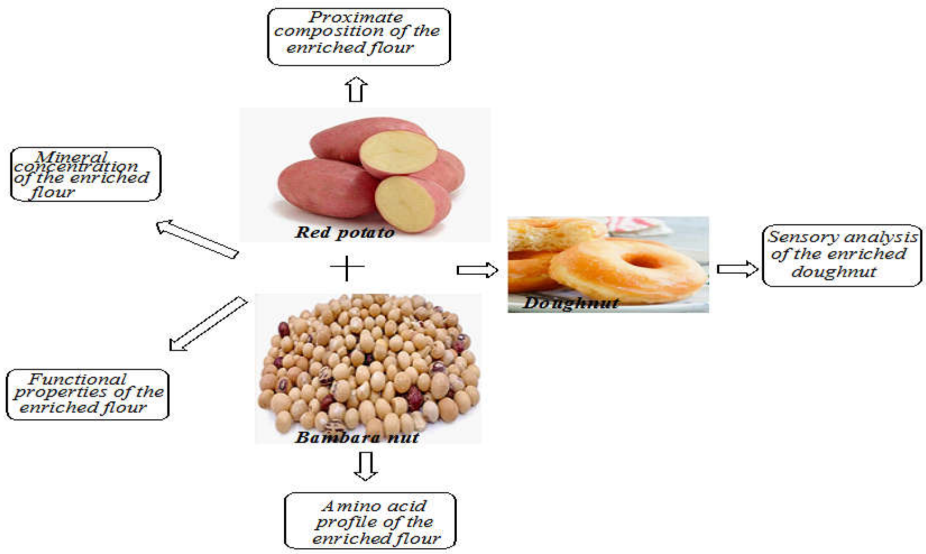
* Corresponding author: Godfrey Okechukwu Eneogwe
✉ E-mail: godfrey.eneogwe@fulokoja.edu.ng

G R A P H I C A L A B S T R A C T



Introduction

Even though food is abundant on the planet, many poor countries nevertheless have high rates of hunger. The two main concerns of the World Health Organization (WHO) and UNICEF are protein energy malnutrition (PEM) and micronutrient deficiencies in newborns, children and expectant mothers. In underdeveloped nations, malnutrition is a leading cause of illness and has been connected, either directly or indirectly, to over 50% of pediatric fatalities [1]. James *et al.* [1] claim that most regional supplemental diets given to developing infants are low in energy, protein, essential amino acids, and minerals. Newborns find it difficult to utilize nutrients since they often contain high amounts of dietary fiber and antinutrients. Malnutrition is rampant as a result, leading to major health issues related to nutrients. 30-40% of preschool mortality in Nigeria is linked to malnutrition [2]. Complementary foods are frequently prepared from starchy tubers like cocoyam and sweet potatoes, as well as grains like millet, corn, sorghum, and rice, in developing nations like Nigeria. Eating these starchy foods, which are deficient in calories, protein, vital amino acids, and micronutrients, has consequently been linked to immune system weakness, nutrient-related disorders, and slower body growth in infants [3]. Adedokun *et al.* [4] claim that 50% of pediatric diseases and deaths in underdeveloped countries are caused by protein-energy malnutrition and micronutrient deficiencies in newborns, children, and pregnant women. Young children in developing nations can now easily get affordable, healthful dietary supplements because of the efforts of nutritionists and food scientists working at both the individual and organizational levels [5].

Food research has focused a lot of attention on developing fortified foods since consumers are becoming more interested in foods with high nutritional content and useful qualities. Thus, adding legume-based protein to diets based on tubers has generated a lot of attention. This is because lysine and total protein content in tuber proteins are frequently low [6]. When combined with less expensive and more accessible plant protein sources, such as legumes and oilseeds, tuber proteins can have a higher nutritious value. Nigerian snack foods, such as puff-puff, doughnut, and chin-chin, are less well-known than bread, but they have a lot going for them. They are widely consumed, have a long shelf life and are of high quality. These snack item's added protein content may appeal to certain target audiences, especially those involved in child-feeding initiatives and lower-class communities. The legume known as Bambara nut (Vigna subterranean L.), which is widely cultivated in

Nigeria, is often underutilized despite its many uses. Among its disadvantages are its difficulty in cooking, strong beany flavor, anti-nutrient content, and poor dehulling and milling qualities [7]. Nonetheless, it is most commonly pounded into flour and used to make several dishes, such as bean cakes (akara), paste cooked into a gel (moi-moi or okpa), and composite flour [8]. It has a high protein content (14-24%) and phosphorus content (380 mg/100 g), according to Adebayo-Oyetoro et al. [9]. The required amino acids are balanced, and the seed grain contains a relatively high proportion of lysine (6.6%). Bambara nuts contain more of the essential amino acid methionine in their protein than other grain legumes like peanuts, although having less than half the oil content. Thus, to offer a balanced profile of amino acids, Bambara groundnut could be employed in addition to cereal grains and tubers. Red potato tubers (Solanum tuberosum L.) are one of the most significant and commonly consumed foods in the world because they not only provide calories, but also have several biologically relevant components [10]. Red potatoes (Solanum tuberosum), according to Zhou et al. [11], are a high-yielding, carbohydrate-rich crop that also includes minerals, vitamin C, phytochemicals, high-quality protein, dietary fiber, and selenium.

Due to urbanization, Nigerians are consuming more doughnuts, a ready-to-eat traditional food made of dough [12]. Due to its quickness, flavor, affordability, and high nutritional value, doughnuts are popular with people of all ages, but notably with children and kids in institutions [9]. Furthermore, doughnuts are renowned for their round, soft, and chewy insides. This well-liked snack is frequently offered during gatherings or as a decadent treat at any time of day. Enhancing the nutritional value of doughnuts by adding Bambara nut flour would also increase the product's use of the nut.

Therefore, this study was conducted to create composite flours by blending red potato flour and Bambara nut flour, evaluate their functional properties, proximate composition, and amino acid profile, as well as identify the sensory characteristics of the doughnut samples made from the flour blends.

Experimental

Collection of samples

The study used Bambara nuts (Vigna subterranean L.) that were bought at Lokongoma market in Kogi State, Nigeria, while other ingredients including red potatoes (Solanum tuberosum L.) were bought at Lokoja international market. Dust, debris, stones, and damaged seeds were eliminated from the samples through cleaning. All of them were transported to the laboratory in sanitized polyethylene bags so they could be used later.

Preparation of samples

Preparation of red potato flour sample

Using a stainless-steel slicer, the red potato tubers were sliced into 2 cm pieces. The flesh was then carefully cooked for 15 minutes at 100 °C to prevent browning. The samples were split into 2 cm^3 cubes, which were then allowed to air dry for around 4 days at room temperature. Following reduction to a fine powder, these samples were placed in a resealable polyethylene bag and refrigerated until additional examination.

Preparation of bambara nut flour

To get rid of trash and other objects, the Bambara nuts were washed. The nuts were spread out uniformly and left to air dry at ambient temperature. Using a nutcracker, the Bambara nuts were shelled. After that, a mortar and pestle were used to pound this until it was uniformly thick. After being further sieved using a 2.0 mesh seize sieve to achieve an even more powdered texture, the Bambara nut was sealed in an airtight container.

Preparation of blends of red potato flour and Bambara nut flour

The following ratios of red potato flour to Bambara nut were blended (%, w/w): 100:0, 90:10, 80:20, 70:30, and 60:40. A Kenwood mixer was used to help homogenize the samples so that they were uniform. To increase the doughnut's nutritious content, the formulation was made.

Preparation of doughnut

As stated earlier, red potato flour and Bambara nut flour were combined before doughnut preparation. A slightly modified version of the recipe as given by Adebayo-Oyetoro et al. [9] was used to make the doughnut samples. The basic recipe consists of 40% fat, 30% blended flour, 1 egg, 10% sugar, 10% yeast, and 20% milk. The red potato-Bambara nut flour was transferred to a sterilized basin, and baking fat was added and well mixed. After dissolving the yeast in the pre-diluted milk, the flour, sugar, egg, and salt were combined. After the dough was properly mixed and kneaded, it was carefully kept in a warm atmosphere until it was time to proof. Doughnuts are made by deep-frying dough in heated vegetable oil. This procedure was carried out for each flour blend to obtain unique doughnut samples.

Determination of proximate composition

The moisture content, crude protein, crude fibre, percentage fat, and ash content were determined using standard analytical techniques as outlined by AOAC [14]. The difference was used to compute the carbohydrate content.

Determination of mineral concentration

When digesting samples for mineral analysis, the AOAC [14] protocol was adhered to. A 250 cm^3 beaker was filled with the ground sample after it had been weighed to 1.00 g. The beaker received an addition of 15.00 cm^3 of concentrated HNO^3 and 5.00 cm^3 of concentrated perchloric acid. The mixture was heated on a hot plate until a clear digest developed after it had been thoroughly stirred to ensure adequate mixing. The digest was allowed to cool before being quantitatively filtered into a 100 cm^3 volumetric flask. When the filtrate's volume reached 100 cm^3, it was transferred into a plastic bottle and sucked into the apparatus meant for trace metal analysis.

Determination of Functional Properties

Dispersibility

Kulkarni et al. [15] devised a method for determining flour dispersibility. The same measuring cylinder was used to weigh 10 grams of flour and 100 cm^3 of distilled water. The setup was shaken fiercely for one minute. The settled particle volume was measured following the standard 30-minute period. One hundred was subtracted from the number of settling particles. A dispersion percentage was used to represent the difference.

Bulk density

The bulk density was computed using the Arise et al. [16] approach. A measuring cylinder with a capacity of 100 cm^3 was filled with 50 g of samples. After that, until the measuring cylinder reached a predetermined volume, it was tapped repeatedly on a lab table. To get the bulk density, the following formula was applied:

$$\text{BD (g/cm}^3\text{)} = \frac{\text{Weight of sample}}{\text{Volume of sample after taping}} \quad (1)$$

Water absorption capacity (WAC)

The methods outlined by Onwuka [17] were used to calculate the sample's flour water absorption capacity. 10 cm^3 of distilled water and one gram of flour sample (M_o) were added to a centrifuge tube. The centrifuge tube's contents were shaken for thirty minutes in a KS 10 agitator. After centrifuging the mixture for 15 minutes at 5000 rpm, it was placed in a water bath (MEMMERT) for 30 minutes at 37 °C. Before being measured, the sediments that were created (M_2) were dried to a constant weight (M_1) at 105 °C. After that, the following formula was used to determine WAC:

$$\text{WAC (\%)} = \frac{\text{Weight of the water added to the sample} - \text{Weight of the water removed from sample}}{\text{Weight of flour sample}} \times 100 \quad (2)$$

Oil absorption capacity (OAC)

The oil absorption capacity of the sample was assessed using methods proposed by Onwuka [17]. A centrifuge tube of 20 cm^3 in volume and weighed was filled with 1 g of the sample (M_o) and 10 cm^3 of oil. The slurry was combined in a vortex mixer for two minutes, and then it was centrifuged for thirty minutes at 4500 rpm while being kept at 28 °C. The transparent supernatant had been decanted and discarded. The tube was weighed after any oil drops that had adhered to it were scraped off (M_1). How the OAC was calculated is as follows:

$$\text{OAC (\%)} = \frac{\text{Weight of the oil added to the sample} - \text{Weight of the oil removed from the sample}}{\text{Weight of the flour sample}} \times 100 \quad (3)$$

Swelling Capacity

The method was explained by Kaushal et al. [18]. There was one gram of flour inside a graded cylinder measuring 10 cm^3. 5 cm^3 of distilled water was added, and then the sample's volume was measured. The sample stayed in the water undisturbed for an hour. Following swelling, the following volume was measured and approximated:

$$\text{Swelling capacity} = \frac{\text{volume occupied by sample after swelling}}{\text{volume occupied by sample before swelling}} \quad (4)$$

Solubility index

The solubility index of the sample was assessed using methods proposed by Kaushal et al. [18]. In 30 cm^3 of distilled water, 2.5 g of the sample was distributed. A hot magnetic stirrer was used to cook the liquid for 15 minutes at 90 °C while a glass rod was used to stir it. The prepared paste was allowed to come to room temperature before being placed in tarred centrifuge tubes and centrifuged for ten minutes at 3000 g. To weigh the sediment and determine the amount of solids in the supernatant, it was decanted onto an evaporating crucible dish that had been covered with tar. The dry solids weight was obtained by letting the supernatant evaporate at 110 °C for an entire night. Triple-checking the analysis, the solubility index was computed as follows:

$$\text{Solubility index g/g} = \frac{\text{Weight of dissolved solids in supernatant}}{\text{Weight of dry sample}} \quad (5)$$

Gelatinization temperature

To ascertain the level of gelatinization in the sample, various modifications were made to the Lin et al. [19] approach. A, B, and C, three 100 cm^3 conical flasks, were ready. Initially, 50 cm^3 of water and 1.000 g of the sample were added to flasks A and B, while flask C also received 50 cm^3 of water. After being fully gelatinized in a bath of boiling water, Flasks A were quickly cooled to room temperature. After that, flasks A, B and C received an addition of 5 cm^3 of Taka-amylase solution (3 g/100 g). Flask C was regarded as the blank sample. Second, for two hours, the three flasks were submerged in an oscillating water bath set at 37 °C. Thirdly each of the three flasks received 2.00 cm^3 of a 1 mol/cm^3 HCl solution and 2.00 cm^3 of a 1 mol/cm^3 NaOH solution. Each sample was filtered after being diluted with water to a volume of 250 cm^3. Using the 3,5-dinitro salicylic acid colorimetric (DNS) method, the sample's sugar content was finally reduced. The samples were then ten times diluted with a filter. This is how the gelatinization degree was determined:

$$\text{Gelatinization temperature} = \frac{A_b - A_c}{A_a - A_c} \times 100\% \quad (6)$$

Where, A_a is the absorbance of the fully gelatinized sample A; A_b is the absorbance of sample B; and A_c is the absorbance of sample C (blank control). The data were presented as means of three replicate samples.

Determination of amino acid profiles

Using a Soxhlet extractor, 3.00 g of the sample was extracted in petroleum ether at 40-60 °C for six hours to evaluate this [20]. 30.00 mg of defatted samples and 7.00 cm^3 of hydrochloric acid (6.00 mol/dm^3) were put into a glass ampoule. After injecting oxygen into the ampoule and releasing the nitrogen, several amino acids were kept from oxidizing during hydrolysis. Following a 22-hour preheated oven to 105 °C and a Bunsen flame seal, the ampoule was allowed to cool, cracked at the tip, and its contents were filtered. Under vacuum, the filtrate was spun in a revolving evaporator until it dried out at 40 °C. The residue was placed in a plastic bottle and deep-frozen for a whole day after dissolving it in 5.00 cm^3 of pH 2.0 acetate buffer. The Technicon Sequential Multi-Sample (TSM) amino acid analyser received five to ten microliters of the hydrolysate. Pouring this into the analyser's cartridge allowed for 76 minutes of analysis time.

Sensory evaluation

The doughnut samples were examined by a 60-person panel of inexperienced judges from the

Federal University Lokoja community. Scent, appearance, flavor, taste, texture, and overall acceptability were all assessed on a 7-point hedonic scale, with 1 denoting a strong dislike and 7 denoting a strong like [21].

Statistical analysis

The collected research data were statistically analysed with a significant threshold of $p \leq 0.05$ utilizing mean standard deviation analysis of variance (ANOVA), as specified by Duncan's multiple range test, to ascertain the level of significance between various samples.

Results and Discussion

Formulation of red potato and Bambara nut blend

Table 1 presents the sample blend formulation. To treat nutrient deficiency and enhance public health, fortification of basic foods is essential [22]. Despite lacking essential nutrients, red potatoes are a popular tuber crop that are heavy in carbohydrates. However, the Bambara nut is a great source of vitamins, minerals and proteins. The goal of this study is to enhance the nutritional profile of red potatoes-based foods by fortifying them with Bambara nuts. A range of proportions are provided by the chosen ratios (100:0, 90:10, 80:20, 70:30, and 60:40) to assess the effect on the nutritional composition of the fortified yam.

Proximate composition of the red potato/Bambara nut flour blends

The proximate composition of the red potato/Bambara nut flour blend is listed in Table 2. The moisture content of the enriched flour ranged from 8.74 ± 0.10^{b} % for GOE (RPF100:0BNF) to 18.90 ± 0.76^{a} % for PCO (RPF 60:40 BNF). This shows that as the amount of substitution with Bambara nut flour increases, so does the moisture content increase. There was a significant difference ($p \leq 0.05$) in the enriched samples. This finding is consistent with that of Gomes Natal et al. [23], who similarly observed that as enrichment increases, the moisture content of potato bread fortified with whole soybean flour increases. There is evidence that baked food's high moisture content contributes to its short shelf life [24]. The ash content of the enriched flour ranged from 1.94 ± 0.50^{b} % for GOE (RPF100:0BNF) to 3.23 ± 0.50^{a} % for PCO (RPF 60:40 BNF). This shows that as the amount of substitution with Bambara nut flour increases, so also does the ash content increase. A significant difference ($p \leq 0.05$) was seen in the enriched samples. This finding is consistent with that of Ocheme et al. [24], who similarly observed that the amount of ash in wheat flour fortified with groundnut protein concentrate increased with fortification. The degree of mineral stuffing in the food sample can be determined by looking at the ash content, a non-organic molecule [25]. The crude protein content of the enriched flour ranged from 10.87 ± 0.25^{a} % for GOE (RPF100:0BNF) to 29.23 ± 0.25^{c} % for PCO (RPF 60:40 BNF). This shows that as the amount of substitution with Bambara nut flour increases, so does the crude protein content increase. A significant difference ($p \leq 0.05$) was seen in the enriched samples. Similar findings were reported by Ogori et al. [26], who likewise observed that as fortification increased, the protein content of potato-garri supplemented with soy flour increased. The quantity of protein in the sample is indicated by its crude protein content. Thus, helps build and repair bodily tissues [27]. The crude fibre content of the enriched flour ranged from 5.00 ± 0.42^{f} % for PCO (RPF 60:40 BNF) to 21.06 ± 0.16^{e} % for GOE (RPF100:0BNF). This shows a decline in crude fibre content as the amount of substitution with Bambara nut flour increases. A significant difference ($p \leq 0.05$) was seen in the enriched samples. While this finding is not comparable to that of Ogori et al. [26], it did demonstrate a similar decline in crude fibre content with increasing fortification in potato-garri supplemented with soy flour.

Table 1. Sample codes for red potato and Bambara nut formulation

Sample	RPF (%)	BNF (%)
GOE	100	0
OEO	90	10
WAO	80	20
GWI	70	30
PCO	60	40

Notice: RPF: Red potato flour, BN: Bambara nut flour, GOE: (RPF 100:0 BNF), OEO: (RPF 90:10 BNF), WOA: (RPF 80:20 BNF), GWI: (RPF 70:30 BNF), and PCO: (RPF 60:40 BNF)

However, dietary fibre, which supports a man's digestive health and helps prevent obesity, declines when crude fibre declines [25].

The crude fat content of the enriched flour ranged from 6.70±0.41^{b} % for GOE (RPF100:0BNF) to 13.46±0.12^{c} % for PCO (RPF 60:40 BNF). This shows that as the amount of substitution with Bambara nut flour increases, so also does the crude fat content increase. The enriched samples showed a significant difference ($p \leq 0.05$). This result though higher than that obtained by Adebayo-Oyetoro et al. [9], demonstrated the same rise in fat content of doughnuts manufactured from wheat flour supplemented with Bambara nut flour as the fortification increases. Most of the energy that humans require comes from dietary fat [28].

The carbohydrate content of the enriched flour ranged from 30.18±0.25^{b} % for PCO (RPF 60:40 BNF) to 50.69±0.41^{c} % for GOE (RPF100:0BNF). This shows a decline in carbohydrate content as the amount of the substitution with Bambara nut flour increases. There was a significant difference ($p \leq 0.05$) in the enriched samples. This finding, however, is consistent with that of Gomes Natal et al. [23], who observed a similar decline in the amount of carbohydrates in potato bread fortified with whole soybean flour as enrichment increased. All living things are thought to primarily obtain their energy from carbohydrates [29].

Table 2. Proximate composition of red potatoes/Bambara nut flour blends

Samples	Moisture content (%)	Ash content (%)	Crude fat (%)	Crude fiber (%)	Crude protein (%)	Carbohydrate (%)
GOE	8.74±0.10b	1.94±0.50a	6.70±0.41b	21.06±0.16e	10.87±0.25a	50.69±0.41c
OEO	10.82±0.67a	2.18±0.29f	8.90±0.63f	17.51±0.15c	14.85±0.29b	45.74±0.52b
WOA	12.32±0.25d	2.58±0.29c	9.96±0.26a	13.25±0.79d	18.69±0.25d	43.20±0.55e
GWI	15.61±0.40c	2.91±0.25d	11.32±0.46d	9.00±0.78a	23.56±0.06f	37.60±0.39a
PCO	18.90±0.76a	3.23±0.50a	13.46±0.12c	5.00±0.42f	29.23±0.25c	30.18±0.25b

Key: GOE: (RPF 100:0 BNF), OEO: (RPF 90:10 BNF), WOA: (RPF 80:20 BNF), GWI: (RPF70:30 BNF), and PCO: (RPF 60:40 BNF)

Mineral concentration of red potato/Bambara nut flour blend

The mineral concentration of the red potato/Bambara nut flour blend is displayed in Figures 1 and 2. The calcium content of the enriched flour ranged from 35.73±0.75 mg/kg for GOE (RPF100:0BNF) to 50.44±0.88 mg/kg for PCO (RPF 60:40 BNF). This shows that as the amount of substitution with Bambara nut flour increases, so does the calcium concentration increase. A significant difference ($p \leq 0.05$) was seen in the enriched samples. The finding is consistent with the reports by Nkesiga et al. [30], who similarly noted that the calcium level of infant diets prepared from orange-fleshed sweet potatoes and fortified with soybean flour and amaranth seeds increased with fortification. Calcium is necessary for blood coagulation, muscle contraction, neurological function, and the development of teeth and bones [31]. For adults, the recommended daily intake is 1000 mg of calcium per day, but for children, it's only 500-800 mg [32]. The magnesium content of the enriched flour ranged from 73.85±0.55 mg/kg for GOE (RPF100:0BNF) to 124.10±0.65 mg/kg for PCO (RPF 60:40 BNF). This shows that as the amount of substitution with Bambara nut flour increases, so does the magnesium concentration increase. A significant difference ($p \leq 0.05$) was seen in the enriched samples. The finding aligns with the observations made by Onabanjo and Ighere [33], who also noted an increase in magnesium content in wheat-sweet potato composite flour upon enrichment. Magnesium influences several ailments, including immunological dysfunction, alopecia, dermatitis, growth retardation, poor spermatogenesis, fetal abnormalities and bleeding issues [34]. It is advised to consume 80-320 mg of magnesium daily [32]. The phosphorous content of the enriched flour ranged from 47.00±0.68 mg/kg for GOE (RPF100:0BNF) to 82.62±0.78 mg/kg for PCO (RPF 60:40 BNF). This shows that as the amount of substitution with Bambara nut flour increases, so does the phosphorous concentration increase. There was a significant difference ($p \leq 0.05$) in the enriched samples. This result is in line with that of Onabanjo and Ighere [33], who also noted that enrichment enhanced the amount of magnesium in wheat-sweet potato composite flour. For instance, calcium and phosphorus combine to build children's and nursing mother's teeth and bones [34]. For both adults and children, the recommended daily intake of magnesium is 800 mg [32]. The sodium content of the enriched flour ranged from 35.73±0.75 mg/kg for GOE (RPF100:0BNF) to 50.44±0.88 mg/kg for PCO (RPF 60:40 BNF). This shows that as the amount of substitution with Bambara nut flour increases, so also does the sodium concentration increase. The enriched samples showed a significant difference ($p \leq 0.05$). This result is consistent with that of Eke-Ejiofor et al. [35], who also noted that cookies prepared with cassava and Bambara groundnut flour blends had higher sodium concentrations with increasing fortification. Sodium is a macronutrient that is essential for several metabolic activities, including the stimulation and transmission of nerve impulses during activity, according to Godfrey et al. [27]. The recommended daily intake of sodium from food is 10 mg for adult males and fewer than 15 mg for females [32]. The potassium content of the enriched flour ranged from 35.73±0.75 mg/kg for GOE (RPF100:0BNF) to 50.44±0.88 mg/kg for PCO (RPF 60:40 BNF).

This shows that as the amount of substitution with Bambara nut flour increases, so also does the potassium concentration increase. A significant difference ($p \leq 0.05$) was seen in the enriched samples. This result is in line with the findings of Nkesiga et al. [30], who also noted that the potassium content of ready-to-eat baby foods made from orange-fleshed sweet potatoes enriched with soybean flour and amaranth seeds rose with fortification. The regulation of the body's water balance, immunological response, neurotransmission, and heartbeat is significantly influenced by potassium [36]. It is recommended that adults get 2000 mg of potassium daily, while children should only consume 1000 mg [32].

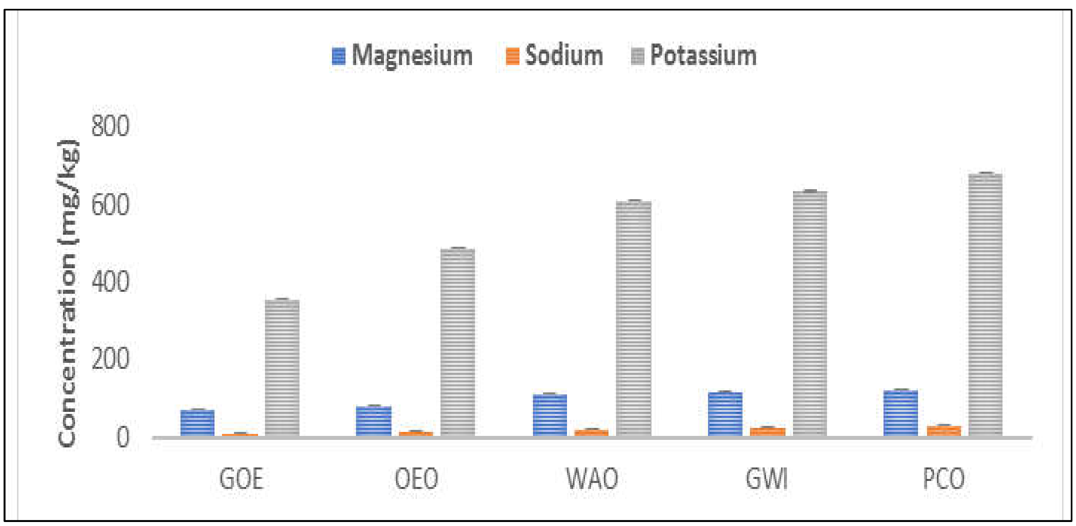


Fig 1. Mineral concentration of red potato/Bambara nut flour blends. GOE: (RPF 100:0 BNF), OEO: (RPF 90:10 BNF), WOA: (RPF 80:20 BNF), GWI: (RPF70:30 BNF), and PCO: (RPF 60:40 BNF)

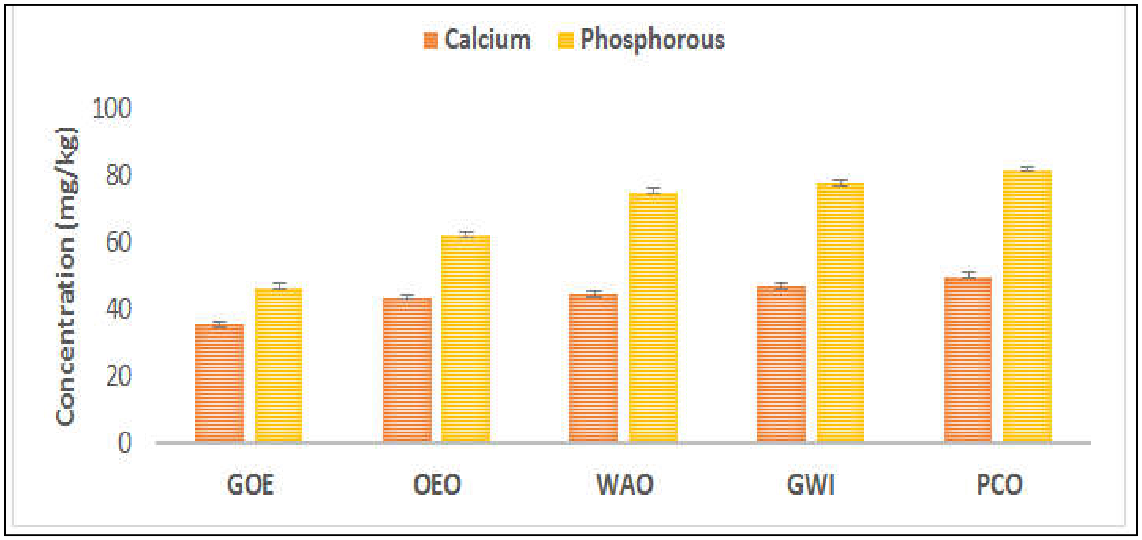


Fig 2. Mineral concentration of red potato/Bambara nut flour blends. GOE: (RPF 100:0 BNF), OEO: (RPF 90:10 BNF), WOA: (RPF 80:20 BNF), GWI: (RPF70:30 BNF), and PCO: (RPF 60:40 BNF)

Functional properties of red potato/Bambara nut flour blend

The functional properties of red potato/Bambara nut flour blends are shown in Figures 3 and 4. The bulk density of the enriched flour ranged from 0.36±0.01[a] g/cm^3 for GOE (RPF100:0BNF) to 0.72±0.02[g] g/cm^3 for PCO (RPF 60:40 BNF). This shows that as the amount of substitution with Bambara nut flour increases, so does the bulk density increase. The enriched samples showed a significant difference ($p \leq 0.05$). However, similar findings were reported by Ogori et al. [26], who also observed that the bulk density of potato-garri supplemented with soy flour increased with increased fortification. Bulk density gives knowledge about the proportionate volume of packing material required, as well as how materials are handled and applied in wet processing in the food industry [37]. The oil absorption capacity of the enriched flour ranged from 5.50±0.43[d] % for GOE (RPF100:0BNF) to 18.80±0.26[a] % for PCO (RPF 60:40 BNF). This shows that as the amount of substitution with Bambara nut flour increases, so also does the oil absorption capacity increase.

This is because the proteins in the flour combine to create complexes with fat or oil molecules. There was a significant difference ($p \leq 0.05$) in the enriched samples. Though this finding was higher than that of Ubbor et al. [38], it nevertheless demonstrated that cookies made from composite flours containing wheat, Bambara nuts, and orange-fleshed sweet potatoes would increase in their ability to absorb water as enrichment increased. The ability of a protein to bind to fat in food compositions is indicated by its oil absorption capability. It is therefore essential for enhancing food's texture and preserving flavor [39]. The water absorption capacity of the enriched flour ranged from 5.10±0.13[b] % for GOE (RPF100:0BNF) to 10.10±0.20[d] % for PCO (RPF 60:40 BNF). This shows that as the amount of substitution with Bambara nut flour increases, so does the water absorption capacity increase because flour's proteins can absorb and retain water. There was a significant difference ($p \leq 0.05$) in the enriched samples. While this finding was not as high as that of Adebayo-Oyetoro et al. [9], it did demonstrate a similar improvement in water absorption capacity as doughnuts made from wheat flour enhanced with Bambara nut as the fortification increased. As per Godswill et al. [40], the water absorption capacity is an essential parameter that indicates the suitability of the flours for use in a range of baking applications, watery food formulations, and product bulking and homogeneity. The swelling capacity of the enriched flour ranged from

12.15±0.03[b] g/g for GOE (RPF 100:0 BNF) to 18.16±0.02[g] g/g for PCO (RPF 60:40 BNF). This shows that as the amount of substitution with Bambara nut flour increases, so does the swelling capacity increase. The enriched samples showed a significant difference ($p \le 0.05$). This outcome is similar to that of Adebayo-Oyetoro et al. [9], who demonstrated that doughnuts made from wheat flour fortified with Bambara nut had a greater potential to rise as the fortification increased. Swelling power, a measure of starch hydration, is used to illustrate the associative binding force in starch granules, according to Godswill et al. [40]. Essentially, it shows how much water starch granules may contain. The gelatinization temperature of the enriched flour ranged from 53.50±1.50[b] °C for PCO (RPF 60:40 BNF) to 65.15±1.20[a] °C for GOE (RPF100:0BNF). This shows a decline in gelatinization temperature as the amount of substitution with Bambara nut flour increases. There was a significant difference ($p \le 0.05$) in the enriched samples. This outcome, however, is similar to that reported by Wang et al. [41], who demonstrated the impact of varying potato flour gelatinization levels on the integrity of gluten network. Starch is more readily available after gelatinization for amylase hydrolysis. It thereby facilitates the starch's digestion [41].

The solubility index of the enriched flour ranged from 2.77±0.02[b] g/g for GOE (RPF100:0BNF) to 5.10±0.03[f] g/g for PCO (RPF 60:40 BNF). Demonstrating a rise in solubility with increasing amounts of Bambara nut flour substitution. There was a significant difference ($p \le 0.05$) in the enriched samples. This result, however, is less than that of Esther et al. [42], who similarly observed an increase in the solubility index with increased fortification. A protein's solubility is an essential functional feature since proteins must be soluble in order to play a critical role in food systems [43].

Amino acid profile of red potato/Bambara nut flour blend

Table 3 indicates the amino acid profile of the red potato/Bambara nut flour blend. Except for aspartic acid, tyrosine, cysteine, and isoleucine, every essential and non-essential amino acid rose as the proportion of Bambara nut flour increased. The fortified samples contained more non-essential amino acids than essential amino acids, according to the data. Non-essential amino acid values were 36.00±0.09 g/100g, 37.99±0.13 g/100g, 40.37±0.08 g/100g, 44.06±0.05 g/100g, and 53.10 ±0.02 g/100g for GOE, OEO, WOA, GWI, and PCO, respectively. These figures show 54.64%, 55.36%, 54.98%, 54.98%, and 54.42%, respectively.

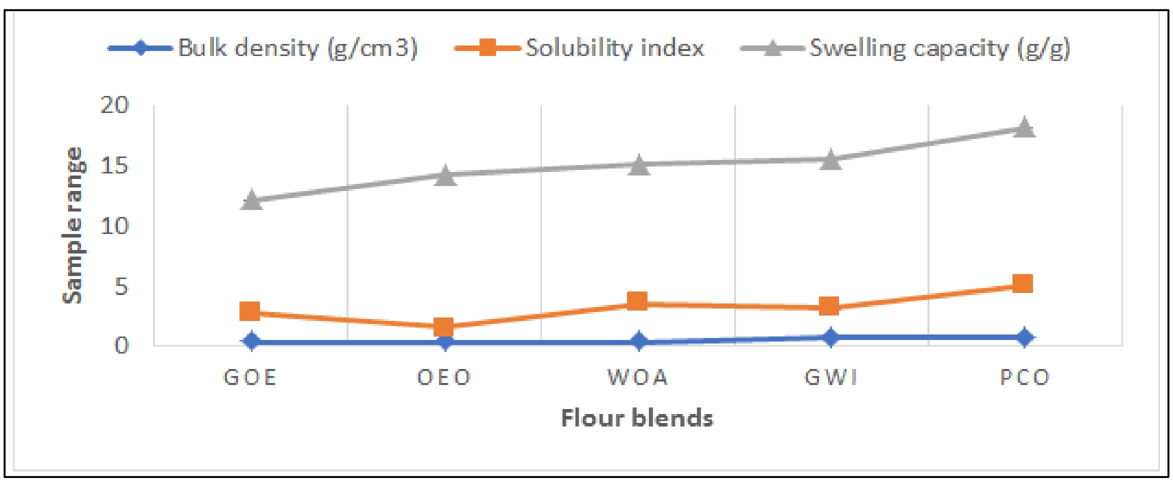


Fig 3. Functional properties of red potato flour and Bambara nut flour blend. GOE: (RPF 100:0 BNF), OEO: (RPF 90:10 BNF), WOA: (RPF 80:20 BNF), GWI: (RPF 70:30 BNF), and PCO: (RPF 60:40 BNF)

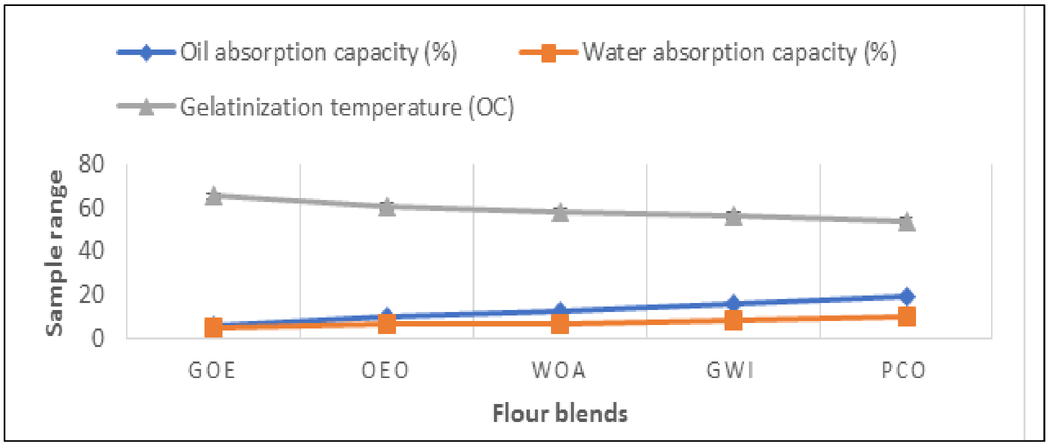


Fig 4. Functional properties of red potato flour and Bambara nut flour blend. GOE: (RPF 100:0 BNF), OEO: (RPF 90:10 BNF), WOA: (RPF 80:20 BNF), GWI: (RPF 70:30 BNF), and PCO: (RPF 60:40 BNF)

The total essential amino acid contents for GOE, OEO, WOA, GWI, and PCO were 29.89±0.13 g/100 g, 30.63±0.11 g/100 g, 33.10±0.02 g/100 g, 36.08±0.04 g/100 g, and 44.47±0.06 g/100 g, which represent 45.36 %, 44.64 %, 45.05, 45.02 %, and 45.58 %, respectively. This outcome, though, is comparable to reports by Adedokun et al. [4].In addition, the sample percentage ratios of essential amino acids (EAA) to total amino acids (TAA) varied from 44.64% to 45.58%. These percentages are far greater than the 39% that are considered essential for an infant, 26% for children and 11% for adults to have an optimal protein diet. With values ranging from 7.57±0.04^{b} g/100g for GOE to 18.41±0.01^{a} g/100g for PCO, glutamic acid seemed to be the most prevalent amino acid across all samples. The proteins production requires glutamic acid, a non-essential amino acid that is utilized by practically all living things. Glutamic acid's primary purpose is to act as a neurotransmitter. In the central nervous system, it functions as an excitatory neurotransmitter to facilitate communication between nerve cells. Glutamate receptors in the brain are involved in learning, memory, and synaptic plasticity [44]. In all the samples examined, tryptophan was the least prevalent amino acid. It is an important amino acid that serves as a solitary precursor to serotonin, a neurotransmitter that controls mood, hunger, sleep and immunity [45]. While 2.5 g/kg/day is not advised, a minimum consumption of 1.5 g/kg/day of amino acids is said to be required to prevent negative nitrogen balance [46].

In summary, adding Bambara nut flour to red potato flour has the potential to yield a beneficial amino acid profile that is higher in nutritional quality and contains a greater variety of important amino acids. These blends have the potential to address global food security and nutrition concerns while helping to satisfy the rising demand for plant-based proteins. In addition, it can aid in the creation of fresh, sustainable human protein sources.

Sensory characteristics of doughnut produced from fortification of red potato flour with Bambara nut flour

Figure 5 illustrates the sensory characteristics of the food samples that were supplemented. A seven-point hedonic scale was used to rate the samples based on their overall acceptability, texture, flavour, aroma, and appearance. As per the findings, the red potato flour samples sensory characteristics are significantly impacted by Bambara nut flour. The fact that the samples quality changed dramatically when the amount of Bambara nut flour increased indicates that Bambara nut flour has a beneficial impact on all of the samples.

Based on the results, sample GOE was found to have the best flavour and taste, measuring 6.53±0.95^{d} and 6.33±1.45^{c}, respectively. However, sample WOA scored 6.91±1.33^{a}, 6.93±0.76[a], 6.44±1.55[c] and 6.46±1.45[d], respectively, for the best aroma, texture, appearance and overall acceptability. These outcomes were largely in line with those of Ubbor et al. [38], who demonstrated how gradually substituting Bambara nuts enhanced the sensory qualities of cookies made using composite flours consisting of wheat and orange-fleshed sweet potatoes.

Table3. Amino acid profile of the red potato/Bambara nut flour blends

Note: Values are means ± standard deviation of triplicate analysis, TEAA - Total essential amino acid, TNEAA -

Amino Acid	GOE g/100g protein	OEO g/100g protein	WOA g/100g protein	GWI g/100g protein	PCO g/100g protein
Leucine	5.02±0.02[b]	5.58±0.01[b]	6.10±0.02[a]	6.65±0.01[c]	7.25±0.02[e]
Lysine	4.14±0.01[a]	4.09±0.01[a]	4.31±0.01[b]	4.65±0.02[b]	6.53±0.02[a]
Isoleucine	3.99±0.02[c]	3.42±0.02[b]	3.12±0.01[e]	2.34±0.03[b]	1.82±0.01[b]
Phenylalanine	4.61±0.03[b]	4.75±0.02[c]	5.14±0.03[b]	5.76±0.02[a]	6.24±0.03[f]
Tryptophan	1.44±0.01[e]	1.34±0.03[b]	1.31±0.02[e]	1.06±0.01[d]	0.91±0.02[b]
Valine	4.97±0.04[d]	5.22±0.01[h]	5.74±0.01[b]	6.40±0.01[b]	7.96±0.01[b]
Methionine	0.96±0.02[b]	0.95±0.02[d]	1.23±0.01[c]	0.93±0.02[c]	0.92±0.01[c]
Threonine	3.19±0.01[c]	3.27±0.01[f]	3.31±0.02[a]	3.64±0.03[d]	5.54±0.04[f]
Histidine	1.57±0.03[a]	2.01±0.02[a]	2.84±0.02[d]	4.65±0.02[a]	7.30±0.03[b]
*Tyrosine	3.96±0.01[d]	3.49±0.01[c]	3.19±0.04[c]	2.56±0.01[c]	2.09±0.02[b]
*Arginine	3.01±0.02[b]	3.32±0.02[b]	3.82±0.01[b]	4.82±0.01[b]	6.69±0.01[e]
*Cystine	1.63±0.05[e]	1.36±0.03[b]	1.51±0.03[a]	0.94±0.02[d]	0.69±0.02[f]
*Alanine	4.06±0.01[a]	4.21±0.01[h]	4.51±0.01[b]	4.68±0.04[e]	4.89±0.02[b]
*Glutamic acid	7.57±0.04[b]	9.53±0.02[c]	10.90±0.05[d]	13.45±0.02[f]	18.41±0.01[a]
*Glycine	2.16±0.01[b]	2.31±0.02[a]	2.33±0.02[b]	2.63±0.03[b]	2.75±0.02[d]
*Proline	3.76±0.02[c]	4.12±0.01[d]	4.16±0.01[e]	5.05±0.01[c]	5.48±0.03[b]
*Serine	3.03±0.01[d]	3.27±0.03[e]	3.84±0.01[b]	4.45±0.01[b]	6.05±0.01[b]
*Aspartic acid	6.82±0.02[e]	6.38±0.02[c]	6.11±0.02[d]	5.48±0.02[d]	4.96±0.01[c]
TEAA	29.89±0.13 (45.36%)	30.63±0.11 (44.64%)	33.10±0.02 (45.05%)	36.08±0.04 (45.02%)	44.47±0.06 (45.58%)
TNEAA	36.00±0.09 (54.64%)	37.99±0.13 (55.36%)	40.37±0.08 (54.95%)	44.06±0.05 (54.98%)	53.10 ±0.02 (54.42%)

Total non-essential amino acid, *Non-essential amino acid, GOE: (RPF 100:0 BNF), OEO: (RPF 90:10 BNF), WOA: (RPF 80:20 BNF), GWI: (RPF 70:30 BNF), and PCO: (RPF 60:40 BNF).

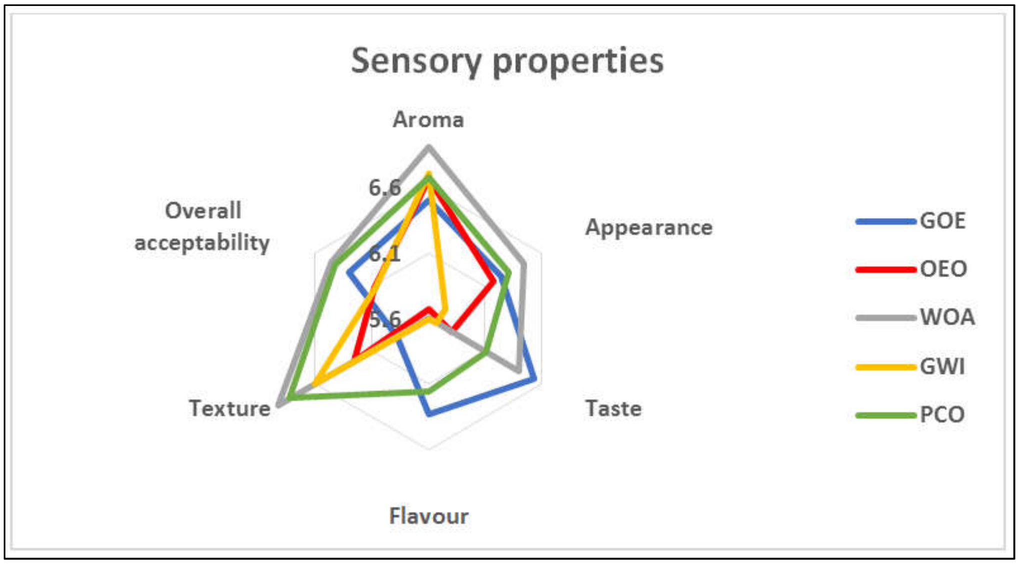


Fig 5. Sensory properties of doughnut produced from red potato flour fortified with Bambara nut flour. GOE: (RPF 100:0 BNF), OEO: (RPF 90:10 BNF), WOA: (RPF 80:20 BNF), GWI: (RPF 70:30 BNF), and PCO: (RPF 60:40 BNF)

Conclusion

This study demonstrated that adding Bambara nut flour to red potato flour improves its nutritional composition and yields flour with a much higher protein content. Consequently, making doughnuts with enriched red potato and Bambara nut flour will increase the use of these legumes and root crops while simultaneously improving the product's nutritional content and reducing Protein Energy Malnutrition (PEM) in underdeveloped nations at a minimal cost.

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Disclosure statement

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ORCID

Godfrey Okechukwu Eneogwe
https://orcid.org/0009-0000-6234-6793
Ejike Onwudiegwu Okpala
https://orcid.org/0000-0002-7518-724X
William Ojoniko Anthony
https://orcid.org/0000-0002-2898-6305
Esther Izihyi Ibrahim
https://orcid.org/0009-0006-2426-2920
Anthony Ugbedeojo Atumeyi
https://orcid.org/0009-0002-8950-184X
Bilkisu idris Abdullahi
https://orcid.org/0009-0003-0402-9281
Faith Obuye
https://orcid.org/0009-0009-6906-6212

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