

Evaluation of Functional, Chemical and Sensory Properties of Okpa Food Product Made from Flours of Raw Bambara Seeds, Raw and Roasted at 100°C for 15mins, 30mins and 60mins

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DOI: <https://doi.org/10.51244/IJRSI.2026.1308000337>

Received: 07 September 2026; Accepted: 12 September 2026; Published: 24 September 2026

ABSTRACT

This study was carried out to evaluate the functional, chemical and sensory properties of Okpa produced from Bambara groundnut (*Vigna subterranea* L. Verdc.) flour subjected to different roasting durations. White/cream Bambara groundnut seeds were processed into unroasted flour and roasted flour at 100°C for 15, 30 and 60 minutes, coded samples A, B, C and D, respectively. Okpa was produced from each flour sample using standardized quantities of flour, palm oil, water, salt, pepper and onion, followed by cooking for 60 minutes. The functional properties, proximate composition and sensory properties of the resulting Okpa products were also evaluated. The data generated were analyzed statistically using One Way ANOVA ($P < 0.05$). The results showed that roasting duration significantly affected the functional properties of Bambara groundnut flour. The unroasted flour generally recorded higher values for water absorption capacity (188.35%), oil absorption capacity (138.36%), emulsification capacity (74.50%), swelling capacity (12.31%), foaming capacity (16.34%), foam stability (96.52%) and solubility capacity (11.58%) than the roasted samples. The proximate composition also varied with roasting duration. Crude protein ranged from 16.60 to 21.08%, with the 15-minute roasted sample recording the highest value, while ash ranged from 3.01 to 4.21%. Crude fibre, fat, carbohydrate and moisture contents ranged from 6.28–8.79%, 4.55–5.67%, 4.29–10.84% and 55.98–58.82%, respectively. The 60-minute roasted sample recorded the highest ash and carbohydrate contents but the lowest moisture and protein contents. Sensory evaluation revealed significant differences among the Okpa samples. The unroasted flour produced the most preferred Okpa, recording the highest scores for colour (8.20), taste (7.90), odour/flavour (7.60), texture (8.20) and overall acceptability (7.70). The 60-minute roasted sample recorded the lowest texture (5.70) and overall acceptability (6.20) scores. Overall, the study established that roasting altered the functional and proximate characteristics of Bambara groundnut flour and influenced the sensory quality of Okpa. Under the conditions employed in this study, unroasted Bambara groundnut flour was most suitable for producing highly acceptable Okpa, while 15-minute roasting showed nutritional advantages, particularly in protein and crude fibre content.

Keywords: Bambara Groundnut, Roasted flours, Okpa food products, chemical quality, sensory properties.

INTRODUCTION

Bambara groundnut seed and the gelled food product from the seed flour are popularly called “Okpa” in south eastern part of Nigeria. This seed legume from the plant, *Vigna subterranea* L. Verde, formally *Voandezia subterranea* L Thouars is of fabaceae family. It is found in Africa, and is a novel legume of African origin grown mainly by subsistence female farmers. It belongs to the Fabaceae family and sub family of faboidea (Bamshaiye et al., 2011). Its distribution is widespread from Senegal to Kenya and Madagascar. It originated from the Sahelian region of present day West Africa, from the Bambara tribe near Timbuktu (who now live mainly in Central Mali). It is known as “jugo” beans in South Africa, “Nyimo” beans in Zimbabwe and “Akwei” in Ghana (Nwanna et al., 2005). It is grown and eaten in Western, Northern and Eastern parts of Nigeria (Barimalaa et al., 2000a). It is

known as “jujiya” or “kwaruru” in Hausa, “Okpa otuanya” in Igbo and “epa-roro” in Yoruba. It is extensively grown in Nigeria and stigmatized as “poor man’s crop” (Barimalaa et al., 1994). Although bambara groundnut is rated as one of the sixteen underutilized Nigerian wild legumes by Rajeev and Karim (2009), reports show that the crop is of great importance nutritionally and has the potential to boost food security. The seed makes a complete food, as it contains sufficient quantities of protein, carbohydrates and lipid (Brough and Azam-Ali., 1992; Brough et al., 1993; Massawe et al., 2005). It is a good source of plant protein containing about 17 – 24 % protein with a good balance of essential amino acids especially Lysine (6.8 %) and methionine (1.3 %), (Barimalaa et al.; 2000b). Its amino acid profile is similar to that of many pulses. Nwokolo (1990) and Williams (1993) reported that the lysine content of bambara groundnut exceeds that of any other legume, presenting bambara groundnut as an excellent additive to cereal based diets. The other major nutrients in the beans include about 50 % carbohydrate (mainly starch), about 6.00 % fat, some minerals, vitamins and some anti-nutritional factors such as trypsin inhibitors and polyphenols (Poulter, 1981). The food application of Bambara groundnut includes its use in composite flour technology (Onuh and Abdusalam, 2009; Abasiokong et al., 2010; Bamshaiye et al., 2011, and Omeire, 2012). Enwere (1998) and Onimawo et al., (2007) reported on its utilization for “Okpa” production. “Okpa”, the gelled product is very popular in south eastern states of Nigeria especially in Enugu State. It is a “ready to eat” food product used for breakfast, snacks and dinner etc, and has become of commercial importance.

Bambara groundnut is used traditionally for the production of “Okpa” food product. However, the “Okpa” production is cumbersome and time consuming. Its hard-to-cook phenomenon, and high degree of anti-nutritional factors do militate against its full exploitation in local dishes (Enwere, 1998). When consumed, it also has a long resident time during digestion. Difficulty in digesting cowpea (*Vigna unguiculata* Walp) has been reported by Okoro and Ukpabio (2004). Other processed products from bambara groundnut seed are rare, being that as an underutilized crop it has not been explored through sustained research as is the case with many edible protein seeds. For instance, Uebersax et al (1991) and Uebersax et al (1989) have suggested some research areas for edible or dietary legumes to include (a) to develop high yielding legume varieties that would be more economically attractive to small subsistence farmers (b) improved nutrient content, especially total protein and sulphur amino acids, (c) increased digestibility, (d) reduction in anti-nutritional factors such as enzyme inhibitors and lectins, (e) reduction of oligosaccharides and indigestible starch and protein that may contribute to flatus production (f) control of storage-induced quality changes (insects, moulds and hard cooking and (g) development of improved food products.

Moreover, the processing of Bambara groundnut at the local level has not been standardized and this usually leads to variation in organoleptic, chemical, physical, nutritional quality and costs. As a result, this study intends to develop a standard procedure/treatment for producing “Okpa” with a view to standardizing product quality and acceptability.

Therefore, the aim of this study is to document the traditional procedure for Okpa food product production, and also to explore the feasibility of improving the production procedure and quality of Okpa food product.

MATERIALS AND METHODS

Sample Collection

The white/cream variety of bambara groundnut (*Vigna Subterranean* L verde) seeds used for study were procured from Enugu Main Market, Enugu state, Nigeria.

Preparation of Raw (Unroasted) Bambara groundnut flour

The raw bambara groundnut flour was prepared by the modified traditional method. During the preparation, four (4kg) bambara groundnut seeds (which had been thoroughly cleaned) was weighed and used. The

cleaned seeds were then milled using Pardun WP 30×G×200 Delma 6.5HP commercial milling machine. This flour was coded sample A.

Preparation of Roasted Bambara Groundnut Flour

The roasted bambara groundnut flour was prepared from the cleaned bambara groundnuts seeds. Twelve kilograms (12kg) of the bambara groundnut seeds were cracked into cotyledons by passing the beans once through the cleaned commercial milling machine. The outputs (cotyledons) were divided into three portions. Each portion was then spread evenly on clean stainless steel baking trays (which were thinly perforated at the base to encourage heat transfer efficiency). The baking trays were then put into the Hobart oven and the cotyledons were roasted separately at 100°C for 15, 30 and 60 minutes respectively. The roasted samples were cooled and milled using the commercial machine as in sample A to produce flours which were coded B, C, and D respectively for this study.

Productions of Okpa food products from the roasted flours:

A 1kg of each of the B, C and D roasted samples, and, Sample A, the unroasted flours, was weighed out into respective clean stainless-steel basin. 330ml of palm oil, and 2L of water per sample at about 45°C was added (in bits to prevent lumping) to each of the samples. Each sample was separately mixed into fairly thick, orange coloured paste/slurry after which, measured salt was also added to each sample and each was thoroughly mixed. With separate measures (about 200ml of each paste/slurry) was scooped into units or wraps using dried plantain leaves wraps. Each wrap was tied with twine, shaken vigorously and then dropped into four different pots seated on lighted burner of Ignis gas cooker (each containing about 5L of water at about 60°C). Each wrap was fully submerged by the water. With about 60 minutes heating from the boiling time, the cooking of Okpa food product was ended and the Okpa wraps were removed from both fire and pot, cooled separately and later analyzed.

Recipe Used For Production Of Okpa Food Products From The Flours:

Ingredient	Value
Flour	100 g
Red Palm oil	33 Ml
Water	200 mL
Salt	3 g
Pepper	3 g
Onion	5g

The Determination of Proximate Composition of the Okpa food product. The crude protein, ash, crude fibre, ether extract, moisture, of samples A, B, C and D were determined using the standard method of AOAC (2010). However, the carbohydrate was obtained by difference. Energy was calculated using the Atwater factors: 4 for carbohydrate, 4 for protein, then 9 for lipids, (Fox and Cameroon, (1989)

Moisture Content Determination

Petri dish were thoroughly washed and dried in the oven at 100°C for 30 minutes and allowed to cool in dessicator and their weights recorded. A 2g of the samples were weighed into the dishes and placed inside the oven at 100°C for 4 hours. After they were removed, cooled in a dessicator and weighed. They were

placed back into the oven, dried for further 30 minutes, cooled and re-weighed. The drying continued until constant weights were obtained.

$$\frac{W_2 - W_3}{W_2 - W_1} \times \frac{100}{1}$$

Where W_1 = Weight of empty dish

W_2 = Weight of dish + sample before drying

W_3 = Weight of dish + sample after drying

Crude Fat Analysis

A Soxhlet extraction unit with a reflux condenser and a small round bottom flask (250ml) was used. The flask was weighed after washing and drying and half filled with light petroleum ether (Boiling point 40-60°C) and fitted back to the unit. Two (2) gram portion of each sample was wrapped with Whatman filter papers and gradually lowered into a thimble then fitted into the reflux flask. The boiling flask containing 200ml petroleum ether was heated with heating mantle for 5h. The ether in the bottom flask, evaporated, condensed in the reflux flask until it filled. Then it refluxed into the boiling flask carrying the extracted fat and oil. Heating was stopped after 5hrs and the bottom flask with solvent was allowed to cool. The ether in the flask was evaporated at 60°C and its oil content was dried. The flask with the oil was reweighed. The difference was used to calculate the percentage (%) of crude fat in the sample.

$$\frac{W_2 - W_3}{W_1} \times \frac{100}{1}$$

Where

W_1 = weight of sample

W_2 = weight of empty flask

W_3 = weight of flask + fat extracted

Crude Protein Analysis

The Kjeldahl method was adopted. Half a gram (0.5) of each dry sample was weighed and placed in a Kjeldahl digestion flask. A blank experiment was also setup involving the digestion of all material except the sample. One table spoon of selenium catalyst was added into each of the flask and mixed with 10ml of concentrated H_2SO_4 . The mixture was heated to red hot temperature under a fumed cupboard for 2hours until a clear solution was obtained. The clear solution (the digest) was transferred quantitatively to 100ml volumetric flask and diluted to mark with distilled water. The digest was mixed with equal volume of 45% NaOH solution in a semi micro kjeldahl distillation apparatus. The mixture was distilled and the distillate collected into 10ml of 40% boric acid solution containing about three (3) drops of mixed indicator, methylene red and bromocresol green. A total of 50ml distillate was collected and titrated against 0.02N H_2SO_4 solution. The above distillation process was also carried on the blank sample. The titer value was subtracted from that of the sample and the difference used to calculate the crude protein as thus; The % of nitrogen content is given by;

$$\%N = (14 \times Na(\frac{VF}{VA})(\frac{100}{W}) \times T$$

Where T = titer less blank

Na = normality of acid used

VF = total volume of aliquot

VA = Aliquot volume distilled

W = Mass of sample analyzed

Thus % crude protein (%P) = %N x 6.25

Crude Fibre Analysis

Two gram (2g) of each defatted samples was boiled in 200ml of 125% H₂SO₄ for 30 minutes. The boiled samples were washed with hot water using a two-fold muslin cloth to retain particles. The retained particles were returned to the flask and boiled again in 200ml of 125% NaOH solution and was again washed with hot water and allowed to cool before being transferred to a weighed porcelain crucible. The samples were transferred to the oven to dry at 105⁰C to a constant weight and were subsequently placed in muffle furnace at 550⁰C for 4h and finally cooled in a desiccator and reweighed. By differences in mass, the mass of the fibre was then determined and used in calculating the percentage (%) fibre.

$$\frac{W_3 - W_4}{W_2 - W_1} \times \frac{100}{1}$$

Where

W1 = weight of empty petri dish

W2 = weight of petri dish + sample

W3 = weight of petri dish + residue before ashing

W4 = weight of petri dish + residue after ashing

Ash Content

A measured mass (2g) of each sample was transferred into a crucible of known weight. The samples in the crucibles were placed in a muffle furnace at a temperature of 550⁰C for 3h until samples were free of carbon. The crucibles were cooled in a desiccator to room temperature and weighed. The percentage (%) ash was calculated as thus;

$$\frac{B_2 - B_3}{B_2 - B_1} \times \frac{100}{1}$$

Where

B1 = weight of empty petri dish

B2 = weight of petri dish + sample before ashing

B3 = weight of petri dish + sample after ashing

Carbohydrate Content

Minerals and vitamins occur in minute quantity. Thus to determine the % carbohydrate content, the sum of the contents, moisture (%M.C), ash (%A), protein (%N), fat (%F) and crude fibre (%C) has been deducted from the total mass and is given by;

$$\% \text{Carbohydrate} = 100 - (\%MC + \%A + \%N + \%F + \%C)$$

The determination of the Functional properties of the BGN flours

Water absorption(WAC) and oil absorption(OAC) properties of the flours were by Nzelu et al.,(2014) and method. Emulsion capacity (EMC) determination was by Beuchat (1977). method; swelling and solubility(SLC) capacity were by Odo and Ishiwu (1999). Foam capacity (FC) was by Coffman and Garcia (1977). method

Sensory Evaluation

The 9-point Hedonic scale for product acceptance testing following the Iwe, (2002) method was adopted. Sensory evaluation of cookies samples from various flour blends was conducted using twenty (20) member untrained panellists drawn from Food Technology students, IMT Enugu. The 9 point hedonic scale was used where 9 = extremely like, 8=like very much, 7=like moderate, 6=like slightly, 5=neither like nor dislike, 4=dislike slightly, 3=dislike moderate, 2=dislike very much, 1=dislike extremely. The test was conducted while the samples were still fresh. The panellists were required to observe the sample, taste and score. Then rinse their mouth with water before tasting another sample/product. The products were analysed based on the following parameters of colour, taste, odour/flavour, texture and overall acceptability.

Statistical Analysis

Significant differences between the mean values of Data obtained was subjected to Analysis of variance (ANOVA) using SPSS version 17 statistical procedure and, significance was accepted at ($p < 0.05$) level of probability.

RESULTS AND DISCUSSION

The results of the flour's functional properties: WAC, OAC, EMC, SWC, foam capacity (FC), foam stability and solubility capacity (SLC) were recorded in Table 1. There were significant $P > 0.05$ differences in the values obtained. The water absorption (WAC) of the flour ranged between 166.79^d and 188.35^a, while the OAC ranged between 125.50^d and 138.36^c. The WAC measured the amount of the flour to absorbed while OAC measured the ability of the flours protein to physically bind fat by capillary action.

Water absorption capacity (WAC) ranged from 162.87 to 188.35%, with the unroasted flour (sample A) recording the highest value (188.35%), while the 15-min roasted flour (sample B) recorded the lowest value (162.87%). Samples C and D recorded 167.33 and 166.79%, respectively. The values for A, B, C and D carried different superscripts, indicating that the treatments were significantly different ($P \leq 0.05$). Overall, WAC decreased by approximately 11.45% from the unroasted flour to the flour roasted for 60 min. The relatively high WAC of the unroasted flour may be associated with the availability of hydrophilic groups in native proteins and carbohydrates that readily interact with water. The reduction following roasting could be associated with heat-induced structural changes in starch and proteins and the loss of moisture during heating. However, the relationship between roasting and WAC is not universal. Mubaiwa et al. (2018) reported that roasting increased WAC of BGN flour, attributing this to protein denaturation and exposure of additional polar binding sites. A recent review also reported that roasting generally increases WAC of BGN flour through protein denaturation. The difference between those reports and the present result may be related to differences in roasting temperature, duration, cultivar, particle size, moisture content and analytical procedure.

Oil absorption capacity (OAC) varied from 125.50 to 138.36%. The unroasted flour recorded the highest value (138.36%), followed by samples B (136.21%), C (129.97%) and D (125.50%). The progressive decline with increasing roasting duration suggests that prolonged roasting reduced the ability of the BGN flour to retain oil. Samples A, B and C had different superscripts and were therefore significantly different ($P \leq 0.05$), while sample D did not carry a superscript in the supplied table; therefore, its statistical relationship should be checked against the original statistical output before making a definitive claim. The overall reduction between A and D was about 9.29%. OAC is influenced by the availability of non-polar side chains of proteins and the physical structure of the flour. Interestingly, this finding differs from Mubaiwa et al. (2018), who found that pre-treatments, including roasting, increased OAC in their BGN

samples. Yusuf et al. similarly reported that roasting altered BGN functional properties and generally increased both water and oil absorption capacities under their experimental conditions. Thus, the lower OAC observed in the present study may reflect the particular roasting conditions used rather than an inherent response of all BGN flour to roasting.

Emulsification capacity (EMC) ranged from 63.67 to 74.50%, with the unroasted flour having the highest value (74.50%) and the 60-min roasted flour having the lowest value (63.67%). Samples B and C had values of 67.53 and 67.41%, respectively, while sample D recorded 63.67%. The different superscripts indicate significant differences ($P \leq 0.05$) among the treatments. There was an overall decrease of approximately 14.54% between the unroasted and 60-min roasted samples. The reduction in emulsification capacity with roasting may be associated with heat-induced protein denaturation and reduced protein solubility, which can reduce the ability of proteins to migrate to and stabilize the oil–water interface. This observation agrees strongly with Mubaiwa et al. (2018), who reported that pre-treatment decreased the emulsification capacity and stability of BGN flour, with dry roasting producing a particularly pronounced decline. Yusuf et al. also reported that roasting generally decreased the emulsification capacity of BGN flour.

Swelling capacity (SWC) ranged from 11.83 to 12.31%. The highest value was recorded in the unroasted flour (12.31%), whereas the lowest value occurred in the 60-min roasted flour (11.83%). Samples A, B, C and D were assigned different superscripts, indicating that roasting duration produced significant differences ($P \leq 0.05$). The reduction from A to D was relatively small, approximately 3.90%, compared with the reductions observed for WAC, OAC, EMC and foaming capacity. The decline in swelling capacity may be related to heat-induced changes in starch structure and protein–starch interactions. This is consistent with the recent work of Oladimeji and Adebo (2024), who reported that roasting reduced the swelling power of BGN flour. They attributed the changes to processing-induced modifications of the flour's structural and chemical characteristics.

Foaming capacity ranged from 14.27 to 16.34%. The unroasted flour recorded the highest foaming capacity (16.34%), followed by samples B (14.86%), C (14.70%) and D (14.27%). The values decreased progressively with increasing roasting duration, representing an overall reduction of approximately 12.67% between the unroasted and 60-min roasted flours. Samples A and B were significantly different ($P \leq 0.05$), while samples C and D, as presented, lacked superscripts; consequently, the statistical comparison involving C and D should be verified from the original ANOVA/Duncan output. The decrease in foaming capacity can be associated with protein denaturation and reduced protein solubility resulting from heat treatment. Proteins must generally be sufficiently soluble and flexible to rapidly migrate to the air–water interface and form a stable film around air bubbles. Mubaiwa et al. (2018) reported a decline in foaming capacity in roasted BGN flour, supporting the present observation. Yusuf et al. also reported that roasting reduced the foaming capacity of BGN flour.

Foam stability ranged from 89.85 to 96.52%. The highest value was obtained for the unroasted flour (96.52%), whereas the 60-min roasted flour recorded the lowest value (89.85%). Samples B and C recorded 93.64 and 91.51%, respectively. The different superscripts among A, B and C indicate significant differences ($P \leq 0.05$), while sample D should be statistically verified because no superscript was provided in the table. The reduction from unroasted to 60-min roasted flour was approximately 6.91%. The decrease indicates that prolonged roasting may adversely affect the ability of BGN proteins to form and maintain cohesive interfacial films around air bubbles. The result agrees with studies showing that roasting reduces the foaming properties of BGN flour.

Solubility Capacity ranged from 10.97 to 11.58%, with the unroasted flour having the highest value (11.58%) and the 60-min roasted flour the lowest (10.97%). Samples A, B, C and D were all assigned different superscripts, indicating significant differences ($P \leq 0.05$). The approximately 5.27% reduction observed after 60 min of roasting suggests that prolonged heating modified the property represented by SLC. The solubility capacity reduction can reasonably be associated with heat-induced protein denaturation and aggregation, which reduces the availability of soluble protein fractions. The present result agrees particularly well with Yusuf et al. (2008), who investigated raw and roasted Nigerian Bambara groundnut flour at

different roasting temperatures and times. They reported that roasting generally lowered nitrogen solubility of BGN flour. They further observed that nitrogen solubility was lowest around pH 5 for BGN flour, indicating the importance of protein charge and pH in determining solubility. The agreement with the present result suggests that prolonged thermal treatment can progressively decrease the amount of soluble protein in BGN flour. Similarly, Mubaiwa et al. (2018) reported that roasting negatively affected functional properties of BGN flour and associated the reduction in functionality with heat-induced changes in proteins. Their study showed that roasting reduced foaming properties and emulsification characteristics, properties that are closely related to protein solubility. They explained that roasting exposes hydrophobic regions of proteins and can reduce their ability to remain soluble in the aqueous phase.

Crude protein

The crude protein content ranged from 16.60 to 21.08%. Sample B (15-min roasted flour) recorded the highest protein content ($21.08 \pm 0.32\%$), followed by sample A (unroasted flour) with $18.00 \pm 0.35\%$, sample C (30-min roasted flour) with $17.97 \pm 0.41\%$, and sample D (60-min roasted flour) with the lowest value ($16.60 \pm 0.32\%$). Although samples A and C, were not significantly different from each other. The initial increase in protein from 18.00% in the unroasted flour to 21.08% after 15 min of roasting may be explained partly by moisture loss during roasting, which concentrates the remaining nutrients on a percentage basis. Heat treatment can also alter the accessibility of protein to analytical reagents. However, prolonged roasting resulted in a decline in protein to 17.97% at 30 min and 16.60% at 60 min. Severe or prolonged heating can promote protein denaturation, aggregation and interactions with other food constituents, potentially affecting protein recovery during proximate analysis. The protein range obtained in this study is within the broad range reported for BGN. BGN is recognized as a relatively protein-rich legume, with protein levels commonly reported around 15–25%, depending on genotype, growing conditions and processing. Mubaiwa et al. (2018) reported substantial protein content in BGN flour and demonstrated that processing, including roasting, modifies its nutritional and functional characteristics. More recent research similarly indicates that thermal processing can modify BGN protein structure and functionality. These protein contents fall within the levels earlier reported by Ojimekwe, (2009) among others. The sample B with 15min roasting at 100°C , had the highest crude protein content while sample D with 60mins roasting time had the least crude protein content. The order of the protein levels was $B > A > C > D$. The heat treatments resulted in an increase in the protein content of sample B, as can be seen from Table 1, than is the case in the control (A). For the roasted samples, the protein values decreased with increase in roasting times. Although the protein value of sample A was higher than that of sample C, there was no significant ($P < 0.05$) difference. The protein values obtained in this is higher than the 8.21% to 8.42%, and the 10.5% reported by Thomas and Okoro (2022) and Davidson et al (2019) respectively from unroasted BGN flours, and analysed also on wet weight basis. Heat is the most common physical agent capable of denaturing proteins (Fennema (1985). This thermal denaturation can also cause chemical alteration of amino acid residues through dehydration, deamination and new intra-or intermolecular covalent cross-links' formation. These changes can alter the nutritive and functional properties of proteins, Fennema (1985).

Ash

The ash content ranged from 3.01 to 4.21%. Sample D, roasted for 60 min, had the highest ash content ($4.21 \pm 0.10\%$), followed by sample C ($3.61 \pm 0.12\%$), sample A ($3.54 \pm 0.08\%$) and sample B ($3.01 \pm 0.07\%$). All treatments had different superscripts (a, b, c and d), indicating that the differences were statistically significant ($P \leq 0.05$). The relatively high ash content of sample D may be associated with the substantial moisture loss that occurs during prolonged roasting. Since ash is expressed as a percentage of the sample weight, removal of water and other volatile components can increase the relative concentration of mineral matter. The irregular pattern, however, suggests that factors other than simple moisture concentration may also have contributed to the differences. The values obtained are comparable with reported ash contents for BGN flour. BGN contains appreciable amounts of minerals such as potassium, phosphorus, magnesium, calcium and iron, although the exact mineral concentration varies with variety and processing. Mubaiwa et al. (2018) noted that processing affects the nutritional composition and functional properties of BGN flour.

Thus, the increase in ash observed after prolonged roasting suggests that roasting can modify the relative concentration of mineral constituents without necessarily increasing the absolute quantity of minerals.

Crude fibre

The crude fibre content ranged from 6.28 to 8.79%. The highest value was observed in sample B ($8.79 \pm 0.010\%$), followed by sample A ($6.85 \pm 0.19\%$), sample D ($6.73 \pm 0.29\%$) and sample C ($6.28 \pm 0.12\%$). Samples A, B and C carried different superscripts, indicating significant differences ($P \leq 0.05$). Sample D has no superscript in the supplied table, so its statistical relationship with the other treatments should be verified from the original mean-separation output before making a definitive claim. The increase in crude fibre from 6.85% in the unroasted flour to 8.79% after 15 min roasting may be partly attributable to concentration resulting from moisture loss and changes in the accessibility of structural carbohydrate fractions during heating. The subsequent decline at 30 and 60 min may indicate degradation or modification of some heat-sensitive components or differences associated with the roasting process. The crude-fibre values indicate that BGN flour can make a meaningful contribution to dietary fibre in Okpa. BGN has been described as containing considerable dietary fibre in addition to its protein and mineral content. Processing can alter the fibre fractions and consequently modify the measured crude-fibre content. The fat content obtained in this study was higher than the mean values of 2.30% reported by Thomas and Okoro (2022). However, the ash percent in this study is lower than the 8.1% reported by Davidson et al., (2019). During the flour production, the BGN seeds were passed thrice through the attrition mills and had two sieving cycles, This significantly reduced the seed coat, which constituted the potential crude fibre source for BGN flours.

Fat

The fat content ranged from 4.55 to 5.67%. Sample C recorded the highest fat content ($5.67 \pm 0.16\%$), closely followed by sample D ($5.64 \pm 0.08\%$), while sample A recorded $5.22 \pm 0.15\%$ and sample B had the lowest value ($4.55 \pm 0.07\%$). The order was $B > A > D > C$. This result was higher than in the report of Thomas and Okoro (2022), who reported 1.72% for crude fibre. Samples A, B and C had different superscripts and therefore differed significantly ($P \leq 0.05$). Samples C and D were not significantly different from each other. The relatively higher fat values in samples C and D may partly result from concentration caused by moisture loss during roasting. Roasting can also disrupt cellular structures and alter the association between lipids and proteins or carbohydrates, potentially influencing extractability of lipids during analysis. The reduction observed in sample B may reflect differences in the extent of these changes at the shorter roasting period. The fat values obtained are within the range generally reported for BGN, which contains moderate amounts of lipid compared with oilseeds. The presence of fat contributes to the energy value of BGN and may also influence flavour and mouthfeel of Okpa. This result may be said to agree with the 9.2% crude fibre reported by Davidson et al., (2019) who also added uzuz seeds' (*Piper guineense*) in the flour for the OFP production. The seed coats passed through the sieves with the flour. Bambara groundnut is often credited with 6-8% fat (Fasayiro et al., (2012); Ojmelukwe (2009), Minka and Bruneteau (2000). Thomas and Okoro (2022) who analysed vended OFP from Nsukka area of Enugu state, and Davidson et al., (2019), who produced laboratory OFP using the local recipe (standardized) from Nsukka area too, reported a mean value of 6.17% and, 8.7% respectively.

Carbohydrate

The carbohydrate content ranged from 4.29 to 10.84%, with sample D recording the highest value ($10.84 \pm 1.80\%$), followed by sample A ($8.74 \pm 1.12\%$), sample C ($7.65 \pm 0.27\%$) and sample B ($4.29 \pm 0.36\%$). All four samples had different superscripts, indicating significant differences ($P \leq 0.05$). The carbohydrate values show a marked variation with roasting duration. The lowest carbohydrate value was observed in the 15-min roasted flour, whereas the highest occurred after 60 min. Because carbohydrate in proximate analysis is commonly determined by difference, changes in protein, ash, fibre, fat and moisture will automatically influence the calculated carbohydrate value. Consequently, the observed variations should not necessarily be interpreted as direct destruction or formation of carbohydrate during roasting. The relatively high carbohydrate value in sample D may therefore be associated with the corresponding changes in its other proximate components, particularly its lower moisture content and higher ash and fat values. BGN contains

starch and other carbohydrate fractions that contribute to its nutritional and technological properties. Their values were higher than the result of this study. The carbohydrate contents in this study, ranged between $10.84 \pm 1.80\%$ and $4.29 \pm 0.36\%$ and, Sample D had the highest content while sample B had the least carbohydrate content. The order was $D > A > C > B$. Mean value of 11.35% and 11.6% carbohydrate contents of Okpa food product were reported by Thomas and Okoro (2022) and Davidson et al (2019) respectively.

Moisture content

Moisture content ranged from 55.98 to 58.82% . Sample C had the highest moisture content ($58.82 \pm 0.26\%$), followed by sample B ($58.28 \pm 0.08\%$), sample A ($57.65 \pm 0.63\%$) and sample D, which had the lowest moisture content ($55.98 \pm 0.38\%$). All four samples had different superscripts, indicating significant differences ($P \leq 0.05$). The lower moisture content of the 60-min roasted flour is expected because prolonged exposure to heat promotes evaporation of water. The relatively high moisture values observed in samples B and C may reflect differences in the moisture retention and subsequent cooling or equilibration of the flour. Moisture content is important because it influences storage stability, microbial growth, chemical reactions and shelf life. The reduction in moisture from 58.82% at 30 min to 55.98% at 60 min indicates that prolonged roasting eventually produced appreciable moisture removal. The low moisture associated with longer roasting could potentially improve the storage stability of the flour by reducing the amount of water available for microbial growth and some deterioration reactions. These values were lower than the 60.45% of Davidson et al., (2019) and, the 70.21% moisture content of Thomas and Okoro (2022). At this moisture level, the product would be unstable during storage.

Energy value

The energy value ranged from 745.88 to 787.25 kJ/100 kg as reported in the table. Sample D recorded the highest value (787.25 ± 0.30), followed by sample A (761.63 ± 0.035), sample C (750.25 ± 0.31) and sample B (745.88 ± 0.035). The different superscripts indicate that all four samples were significantly different ($P \leq 0.05$). The highest energy value in sample D may be related to its relatively higher fat and carbohydrate contents. Since energy value is calculated principally from the energy-contributing macronutrients, variations in protein, fat and carbohydrate can produce corresponding differences in calculated energy. The low energy value in sample B corresponds with its relatively low fat and carbohydrate contents. Energy values for foods are ordinarily expressed as kJ/100 g, not kJ/100 kg. If the values really are 745.88 – 787.25 kJ/100 kg, they would be exceptionally low for a food. You should therefore verify whether the intended unit is kJ/100 g or perhaps kcal/100 g before including the table in your thesis. According to FAO (1982), the gross energy value of BGN seed is greater than that of other common pulses such as cowpea, lentil, kidney beans and pigeon pea.

Sensory Evaluation Results

Table 1 also shows the results on the effects of roasting on the W/C flours, on the sensory properties of “Okpa” food products. The samples were tested for color, taste, flavour, texture and overall acceptability. The OFP samples competed well but there was significant $P > 0.05$ differences among the samples. Although roasting improves the flavor, texture and nutritive value of legumes. (Jackson et al., 2013; Fasoyiro et al., 2012), the OFP from the unroasted flour (sample A) was however most preferred to other samples. It had the highest mean score for colour, taste, flavor, texture and overall acceptability. The panelist must have found the sensory attributes of samples B, C and D as novels, and consequently preferring the known traditional taste.

Colour

The colour scores ranged from 6.70 to 8.20 . Sample A (unroasted flour) recorded the highest score (8.20 ± 0.80), followed by sample D (7.10 ± 1.20), while samples B and C recorded 6.80 ± 0.90 and 6.70 ± 1.40 , respectively. The different superscripts indicate that the treatments differed significantly ($P \leq 0.05$), except samples B and C, which shared the same superscript and were therefore not significantly different. The higher colour score obtained for sample A suggests that the panellists had a stronger preference for the

colour of Okpa produced from the unroasted BGN flour. Roasting can modify the colour of legumes through Maillard reactions, caramelisation and other heat-induced chemical changes, with the intensity of these changes depending on roasting temperature and duration. Consequently, progressive thermal treatment can alter the original colour of BGN and subsequently influence consumer perception. The relatively higher colour score of sample D compared with samples B and C indicates that the relationship between roasting duration and colour preference was not strictly linear. This could be because moderate browning may sometimes produce an attractive appearance, whereas excessive browning may be perceived negatively. Processing studies on BGN have demonstrated that thermal treatment changes the physicochemical characteristics of the flour, including properties associated with appearance and colour. Oladimeji and Adebo (2024) reported significant effects of processing conditions on the properties of BGN flour. The present finding is also relevant to Okpa specifically. Barimalaa et al. (2005) demonstrated that the characteristics of BGN flour influence the sensory quality of Okpa, confirming that the properties of the flour used in preparation can translate into differences in the final steamed product.

Taste

The taste scores ranged from 6.40 to 7.90. Sample A recorded the highest score (7.90 ± 0.80), whereas samples B and D recorded 6.40 ± 1.40 , and sample C recorded 6.70 ± 1.10 . Sample A had superscript a, while samples B, C and D had superscript b. This indicates that the unroasted Okpa was significantly different from the roasted samples ($P \leq 0.05$), while the roasted samples did not differ significantly from one another. The higher taste score of sample A indicates greater preference for the taste of Okpa produced from unroasted BGN flour. Roasting produces substantial chemical changes that can modify the flavour profile of legumes. Although moderate heating may generate desirable roasted flavours through Maillard reactions, prolonged heating may produce stronger roasted, bitter or burnt flavour notes, depending on the severity of treatment. Such changes can reduce consumer preference. The reduction in taste scores following roasting is therefore likely associated with heat-induced modification of flavour compounds. The result is particularly relevant because Okpa has a characteristic sensory profile, and changes in the raw material can affect the final product. Barimalaa et al. (2005) confirmed that BGN flour characteristics influence the sensory properties of Okpa, while more recent research has shown that processing methods significantly influence sensory responses to BGN products. Interestingly, a recent 2026 study reported that processing methods such as roasting and germination significantly affected the sensory properties of BGN, with some processed samples receiving high liking scores. This indicates that roasting does not inherently reduce acceptability; rather, the sensory response depends on the particular processing conditions employed. Thus, the lower taste scores observed in the present study may be attributed to the specific roasting durations and conditions used.

Odour/flavour

The odour/flavour scores ranged from 6.40 to 7.60. Sample A recorded the highest score (7.60 ± 1.10), followed by sample B (7.10 ± 1.20), while samples C and D recorded 6.40 ± 1.10 and 6.50 ± 1.60 , respectively. The odour/flavour was significantly affected by roasting duration ($P \leq 0.05$). The highest score in sample A indicates that the panellists preferred the characteristic odour/flavour of Okpa prepared from unroasted BGN. The progressive decline in scores with increasing roasting duration may be associated with the formation of new volatile compounds during roasting and the possible degradation or loss of desirable native flavour compounds. Roasting can generate characteristic nutty and roasted aromas, but excessive heating may produce strong or undesirable aroma compounds. The lower scores recorded by samples C and D suggest that the longer roasting periods may have produced flavour changes that were less preferred by the panellists. This is consistent with the general observation that sensory quality depends on the intensity of thermal processing rather than simply whether or not a food has been roasted. Studies on Okpa support the importance of processing conditions in determining sensory quality. Asumugha and Ezeibe (2024) evaluated consumer acceptability of steamed paste prepared from processed BGN and found that processing affected the nutritional quality and sensory characteristics of the products.

Texture

Texture scores ranged from 5.70 to 8.20. Sample A recorded the highest value (8.20 ± 0.80), followed by sample B (6.90 ± 0.90) and sample C (6.40 ± 1.30), while sample D had the lowest score (5.70 ± 1.80). Sample A differed significantly from all roasted samples ($P \leq 0.05$). Samples B and C were not significantly different, whereas sample D differed significantly from both. The progressive decline in texture scores with increasing roasting duration indicates that prolonged roasting negatively affected the textural acceptability of Okpa. This may be related to changes in the functional properties of BGN flour during roasting. As shown in Table 1, roasting progressively reduced water absorption capacity, emulsification capacity and solubility capacity. Such changes can influence water distribution, protein functionality and the structural development of the steamed paste. Protein denaturation and aggregation during prolonged heating can modify the ability of flour constituents to interact with water and form the desired cohesive structure during steaming. Consequently, the lower functional capacity of highly roasted flour may have contributed to the lower texture score observed for sample D. This interpretation agrees with the work of Barimalaa et al. (2005), who showed that BGN flour characteristics, including particle-size characteristics, affected the performance and sensory properties of Okpa. Their findings demonstrate that the physical characteristics of the flour can be transferred to the quality of the final steamed product. The present result is also supported by research on processed BGN products. A 2026 study reported significant effects of processing methods on the sensory characteristics of BGN, demonstrating that roasting and other treatments can alter consumer perception of processed BGN products.

Overall acceptability

Overall acceptability scores ranged from **6.20 to 7.70**. Sample A recorded the highest score (7.70 ± 0.70), while samples B and C recorded 6.50 ± 1.40 and 6.50 ± 1.30 , respectively, and sample D recorded the lowest score (6.20 ± 1.30). Sample A was significantly more acceptable ($P \leq 0.05$) than all roasted samples. There was no significant difference among the three roasted samples. The superior overall acceptability of sample A is consistent with its higher scores for colour, taste, odour/flavour and texture. Overall acceptability represents the integrated response of panellists to the sensory characteristics of the product; consequently, the high acceptability score of sample A indicates that its combination of appearance, flavour, aroma and texture was preferred. The overall acceptability values obtained in the present study are comparable with findings from previous Okpa studies in which processing treatments produced significant differences in consumer acceptance. Ukegbu et al. reported that processing and enrichment methods affected the organoleptic properties of Bambara groundnut pudding and that the resulting Okpa samples were generally well accepted by panellists. Similarly, Asumugha and Ezeibe (2024) reported differences in consumer acceptability among steamed BGN paste products subjected to different processing treatments.

Table 1: The mean raw flour's functional properties properties of BGN (Okpa) Food Products made from raw and roasted BGN flours

Parameters	A (Unroasted flour)	B	C	D
WAC %	$188.35^a \pm 0.025$	$162.87^c \pm 0.025$	$167.33^b \pm 0.035$	$166.79^d \pm 0.030$
OAC %	$138.36^a \pm 0.030$	$136.212^b \pm 0.035$	$129.97^c \pm 0.20$	125.50 ± 0.030
EMC%	$74.50^a \pm 0.002$	$67.53^b \pm 0.03$	$67.41^c \pm 0.02$	$63.67^d \pm 0.03$
SWC%	$12.31^a \pm 0.03$	$12.20^b \pm 0.031$	$11.90^c \pm 0.025$	$11.83^d \pm 0.030$
Foam capacity	$16.34^a \pm 0.030$	$14.86^b \pm 0.020$	14.70 ± 0.030	14.27 ± 0.030
Foam stability	$96.52^a \pm 0.020$	$93.64^b \pm 0.030$	$91.51^c \pm 0.020$	89.85 ± 0.030

SLC	11.58 ^a ± 0.030	11.51 ^b ± 0.025	11.22 ^c ±0.025	10.97 ^d ±0.025
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Means ± standard deviations. Result are means of n=3 determinations. Means having different superscripts within the row are significantly different at ($P \leq 0.05$)

Key:

Sample A = Unroasted flour

Sample B = 15 min roasted flour

Sample C = 30 min roasted flour

Sample D = 60 min roasted flour

Table 2: The mean raw flour's proximate composition of Bambara groundnut (Okpa) Food Products made from raw and roasted Bambara groundnut flours

parameters	A (Unroasted flour)	B	C	D
% C. Protein	18.00 ^b ± 0.35	21.08 ^a ±0.32	17.97 ^b ±0.41	16.60 ^c ±0.32
% Ash	3.54 ^c ± 0.08	3.01 ^d ± 0.07	3.61 ^b ± 0.12	4.21 ^a ± 0.10
%crude fibre	6.85 ^b ± 0.19	8.79 ^a ±0.010	6.28 ^d ± 0.12	6.73 ± 0.29
%fat	5.22 ^b ± 0.15	4.55 ^c ± 0.07	5.67 ^a ± 0.16	5.64 ^a ± 0.08
% carbohydrate	8.74 ^b ± 1.12	4.29 ^d ± 0.36	7.65 ^c ± 0.27	10.84 ^a ±1.80
% moisture	57.65 ^d ± 0.63	58.28 ^b ±0.08	58.82 ^a ±0.26	55.98 ^c ±0.38
Energy (KJ/100kg)	761.63 ^b ±0.035	745.88 ^d ± 0.035	750.25 ^c ± 0.31	787.25 ^a ± 0.30

Means ± standard deviations. Result are means of n=3 determinations. Means having different superscripts within the row are significantly different at ($P \leq 0.05$)

Key:

Sample A = Unroasted flour

Sample B = 15 min roasted flour

Sample C = 30 min roasted flour

Sample D = 60 min roasted flour

Table 3: The mean raw flour's sensory properties of Bambara groundnut (Okpa) Food Products made from raw and roasted Bambara groundnut flours

parameters	A (Unroasted flour)	B	C	D
Colour	8.2 ^a ±0.8	6.8 ^c ±0.9	6.7 ^c ±1.4	7.1 ^b ±1.2

Taste	7.9 ^a ±0.8	6.4 ^b ±1.4	6.7 ^b ±1.1	6.4 ^b ±1.4
Odour/flavor	7.6 ^a ±1.1	7.1 ^b ±1.2	6.4 ^c ±1.1	6.5 ^c ±1.6
Texture	8.2 ^a ±0.8	6.9 ^b ±0.9	6.4 ^b ±1.3	5.7 ^c ±1.8
Overall acceptability	7.7 ^a ±0.7	6.5 ^b ±1.4	6.5 ^b ±1.3	6.2 ^b ±1.3

Means ± standard deviations. Result are means of n=3 determinations. Means having different superscripts within the row are significantly different at ($P \leq 0.05$)

Key:

Sample A = Unroasted flour

Sample B = 15 min roasted flour

Sample C = 30 min roasted flour

Sample D = 60 min roasted flour

CONCLUSION

The study demonstrated that roasting duration significantly influenced the functional properties, proximate composition and sensory characteristics of Bambara groundnut flour intended for Okpa production. The functional properties showed that unroasted BGN flour generally had higher water absorption capacity, oil absorption capacity, emulsification capacity, swelling capacity, foaming capacity, foam stability and solubility capacity than the roasted samples. The progressive reduction in several of these properties with increasing roasting duration indicates that prolonged thermal treatment modified the protein, starch and other functional components of the flour. The proximate composition also revealed considerable differences among the treatments. The 15-min roasted flour recorded the highest protein and crude fibre, whereas the 60-min roasted flour had the highest ash and carbohydrate contents and the lowest moisture. These findings indicate that roasting can alter the relative nutritional composition of BGN flour, with the magnitude and direction of change depending on the duration of heat treatment. The sensory evaluation showed that the unroasted BGN flour produced the most acceptable Okpa among the treatments evaluated. It recorded the highest scores for colour, taste, odour/flavour, texture and overall acceptability. The differences among samples were significant for most of the sensory attributes at $P \leq 0.05$. In particular, the 60-min roasted sample had the lowest texture and overall acceptability scores, suggesting that prolonged roasting adversely affected the sensory quality of the product. The study established that although roasting modifies the nutritional and functional characteristics of Bambara groundnut flour, prolonged roasting was not advantageous for the sensory acceptability of Okpa under the conditions used in this study. The unroasted flour produced the most preferred Okpa, while 15-min roasting showed some nutritional advantages, particularly in terms of protein and crude fibre. Therefore, the selection of an optimum treatment should consider the intended nutritional, functional and sensory characteristics of the final Okpa product.

RECOMMENDATIONS

Based on the findings of the study, the following recommendations are made:

- Unroasted Bambara groundnut flour should be considered for Okpa production where the major objective is to obtain a product with high sensory acceptability, particularly in terms of colour, taste, odour/flavour and texture.

- Short-duration roasting, particularly 15 min, may be considered where improved protein and crude-fibre contents are desired, provided that the resulting sensory quality remains acceptable to consumers.
- Prolonged roasting should be avoided or carefully controlled, particularly for periods around 60 min, because it was associated with reduced solubility, water absorption, emulsification and foaming properties and lower sensory scores.
- Further studies should investigate the effects of different roasting temperatures and shorter roasting intervals to establish the optimum combination of temperature and time for BGN flour intended for Okpa production.
- Future research should determine the effects of roasting on antinutritional factors, particularly phytate, tannin, trypsin inhibitor and oxalate, since reduction of these compounds may improve the nutritional quality and protein digestibility of Bambara groundnut.
- Further studies should evaluate the protein digestibility, amino-acid profile, mineral bioavailability and starch digestibility of Okpa produced from roasted and unroasted BGN flour.

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