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Effect of Parboiling and Drying Pretreatment on the Cooking Time and Quality Attributes of Bambara Groundnut

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Abstract

Bambara groundnut (BGN) was separately parboiled for 45 and 90 min, then, sun-, oven-, or freeze-dried. Untreated BGN served as the control. Cooking, physical, chemical, and sensory characteristics were investigated to assess quality. All parboiled-dried samples cooked significantly ($p \leq .05$) faster (43%–86%) than the control. Freeze-dried samples showed significantly ($p \leq .05$) higher L^* values than their sun- and oven-dried counterparts, irrespective of parboiling time. Sphericity and aspect ratio significantly ($p \leq .05$) reduced with all the drying methods, though insignificantly when parboiling was extended from 45 to 90 min. Pretreated BGN had higher protein but lower antinutrient contents. Mineral leaching was minimal at 45 min parboiling. Parboiled-dried BGN cooked samples were generally accepted by the panelists as demonstrated by scores of >6 on a 1–9 Hedonic scale. Combined parboiling and (sun- or oven-) drying presents a practicable strategy for BGN farmers/processors to offer an easy-to-cook product, potentially storable for later food preparation by consumers.

Practical applications

The study provides a useful strategy to farmers/food industries in their quest to meet the increasing demand of consumers for more convenience foods as opposed to the drudgery

associated with the long cooking time of Bambara groundnut. Combined parboiling and drying operations produced Bambara groundnut seeds which cooked 43%–86% faster, and had storable potential for later food preparation. The results from the study may enhance the research efforts in recent times aimed at further promoting the utilization of the crop for better food and nutrition security, particularly in regions where its cultivation is favored.

1 INTRODUCTION

There are several pulses in the tropics which are high in nutritive value, versatile in uses, and comparably advantageous in cultivation, but their utilization is largely restrained by certain inherent properties. Meanwhile, there is hope that consumption of this group of crops would increase in future. This is associated with unguaranteed sustainability of meat supply and advocacy for animal rights, on the one hand, and the identified potentials of pulses in the formulation of nutraceuticals, on the other hand (Schoeninger et al., 2014). A notable example of pulses is Bambara groundnut (BGN) (*Vigna subterranea* L.), which is reportedly higher in market value than other legumes like cowpea and peanut in some communities and, therefore, used as a gift during celebrations (Aviara et al., 2013).

BGN is one of the most favored legumes by resource-limited small farmers and rural households. This is attributed to its good performance on marginal soil, and drought tolerance. Literature shows that the crop contains 49%–63.5% carbohydrate, 15%–25% protein, 4.5%–7.4% fat, 5.2%–6.4% crude fiber, and 3.2%–4.4% ash, earning it the status of a complete food (Murevanhema & Jideani, 2013). BGN is comparable to soybeans in chemical composition (Murevanhema & Jideani, 2013) and superior to peanut in essential amino acids profile (Effa & Uko, 2017). Although the crop is suitable for many culinary applications, Aviara et al. (2013) reported that most consumers in sub-Saharan Africa prefer BGN in the boiled form. Unfortunately, the time-consuming nature generally associated with the preparations of beans, BGN inclusive, majorly hinders their utilization and contributes to their replacement with faster-cooking but less nutritive foods (Siqueira et al., 2013). Consumers' growing needs for quick-cooking and nutritive foods have, therefore, been identified (Schoeninger et al., 2014). This justifies the calls for researches aimed at addressing the hard-to-cook (HTC) property of BGN so that they can be consumed after minimal preparation in the homes with the utmost aim of saving consumers' time and energy.

The HTC phenomenon in legumes develops at high temperatures (30–40°C) and high relative humidity (>75%) during storage, conferring on the seeds longer boiling time (3–4 hr) and higher energy consumption during cooking (Mubaiwa et al., 2017). HTC phenomenon in legumes is associated with structural (autolysis of cytoplasmic organelles and lignifications of middle lamella) and compositional changes (e.g., formation of insoluble pectate and interactions of

proteins and phenolic compounds), which occur in the cotyledons and seed coats. Different physical, chemical, and biological techniques have been adopted to reduce the HTC phenomenon. For instance, the use of pressure cooker has been recommended (Emmanuel et al., 2012) though this may not be practicable among resource-poor consumers. Also, Mubaiwa et al. (2019) recently reported a 13%–20% reduction in the cooking time of BGN when alkaline solutions containing *gowa* (a rock salt used as a food tenderizer) and $NaHCO_3$ salts were used as the cooking media. While this presents a potentially useful strategy to address HTC, more effective but less controversial techniques must be explored, as there are concerns among consumers over the use of *gowa* as a food tenderizer in some parts of West Africa, including Nigeria and Ghana. These concerns are primarily due to consequences such as gastrointestinal problems and impaired sensory properties of food products (Mubaiwa et al., 2018). In the same vein, soaking of BGN seeds in water allows for enhanced water absorption thereby decreasing cooking time, but when done for a longer period, there is a higher loss of some nutrients through leaching into the soak water (Subuola et al., 2012). Furthermore, soaking, when not followed with drying, would not allow for possible storage of the seeds owing to increased moisture content. Therefore, the suitability of soaking is confined to immediate preparation for consumption. Interestingly, dehydration of moist-heat pretreated beans has been reported as a remedy to reduce their cooking time (Schoeninger et al., 2014) and Neha et al. (2017) also showed the use of some enzymes such as hemicellulose along with preprocessing operations (blanching, soaking, and dehulling) as a strategy to shorten the cooking time of soybean.

In the present study, combined parboiling and (sun-, oven-, or freeze-) drying operations were intended to be carried out by BGN farmers, processors, or industries, in order to reduce the final cooking time required to prepare BGN in the home. The effect of these pretreatments on the cookability and selected physical, chemical, and sensory attributes of the seeds were then investigated. Parboiling was expected to result in denaturation of protein and solubilization of pectin, both of which are required to reduce HTC effect (Mubaiwa et al., 2017). The choice of sun-drying was due to its availability as a cheap source of energy for poor-resource farmers while oven-drying may be preferred in the urban area where better control over drying conditions (such as temperature) and from contamination (such as rodents and birds' perching) are desired. Though freeze-drying is quite an expensive technology, it is very useful in determining the extent to which the quality attributes of foods can be best retained during drying, hence, it has found much relevance in basic researches. It is pertinent to note that the long cooking time of BGN is not only a challenge among rural dwellers, but also in urban communities where an increasingly busy lifestyle means higher demands for convenience and quick-to-cook nutritious foods.

2 MATERIALS AND METHODS

Materials

Dried BGN (cream-seeded variety), which had been stored for about 8 weeks at ambient temperature (27 ± 1°C), was obtained from Oja Oba market in Ilorin, Nigeria. The grains were packaged in pre-labeled 3-mil polythene bags, and then, conveyed to the laboratory where processing started immediately.

Methods

2.2.1 Parboiling and drying

BGN was sorted to remove debris, dirt, and damaged seeds. This was followed by washing in potable water (1:2, wt/vol). The seeds were then divided into two batches: the first batch was parboiled (at 100°C using an electric cooker) for 45 min while the second batch was parboiled for 90 min both in potable water (seed-to-water ratio was 1:15, wt/vol). The parboiling durations were selected based on preliminary determination of the cooking time of raw BGN (120 min) and the objective of reducing the final domestic cooking time to <30 min. Following parboiling, the seeds from each batch were drained, cooled (at ambient temperature) and then divided into three batches which were dried (1) in the sun (average of 30°C for 24 hr, within 2 days, 7 a.m.–7 p.m. each day), (2) in the oven (at 50°C for 7 hr), and (3) using a lab-scale freeze-dryer (CHRIST BETA 1-8 LD plus S/N: 19155, *Osterode,* Germany) (−56 for 24 hr) following a prior storage in the freezing temperature (−18°C) for 2 hr. The drying temperature for oven-drying was selected since preliminary trials with higher temperatures impaired the color of the seeds. Furthermore, Schoeninger et al. (2014) had noted 50ºC as the optimal drying temperature in a similar study on carioca beans. Following cooling to ambient temperature, pretreated samples, and the control (untreated raw BGN) were packaged in sealed polythene bags and kept in a cool (4 ± 1ºC) dry place for subsequent analyses. All processing and subsequent quality analyses were done using three replicates, unless noted otherwise.

2.2.2 Quality analyses of parboiled-dried BGN

Cooking time determination

Each of the samples was rinsed with distilled water and cooked in deionized water (100°C) in the ratio of 1:10 (wt/vol) on an electric cooker. BGNs were considered to be fully cooked when the cotyledon could disintegrate on pressing between the thumb and the forefinger (Mubaiwa et al., 2019; Ojimelukwe, 1999).

Determination of physical properties

The color characteristics of the BGN samples were determined using a Minolta Chroma Meter CR- 200b (Minolta Corp., Ramsey, NJ, USA). *L*, a*,* and *b** indicate intensity of lightness/darkness, redness/greenness, and yellowness/blueness, respectively. Prior to color

determination, the colorimeter was calibrated with a standard white plate.

The length (*L*), width (*W*), and thickness (*T*) of 100 randomly selected representative seeds from each sample were measured using a Vernier Caliper with 0.01 mm reading and mean values were calculated. The arithmetic and geometric average diameters, sphericity, surface area, and aspect ratio were determined according to the procedures previously described by Adeyanju and Abimbola (2015):

Arithmetic average diameter (D_a) = $\frac{L+W+T}{3}$;

Geometric average diameter (D_g) = $\sqrt[3]{LWT}$;

Sphericity (Φ) = $\frac{(LWT)^{0.333}}{L}$

Surface area (S) = $\pi D g^2$.

Aspect ratio (R_a) = $\left(\frac{W}{L}\right) \times 100$

Determination of chemical properties

Proximate composition

The proximate compositions of the BGN samples were determined following the procedures described by Association of Official Analytical Chemists (A.O.A.C., 2000).

Mineral analysis

The contents of selected minerals were determined using a modified method described by Oyeyinka (2016). Each of the samples (1 g) was first of all dried at 105°C for 2 hr, then, ashed in a muffle furnace at 600°C for 5 hr. Thereafter, the ash was hydrated with 2 ml of deionized water followed by addition of 2 ml concentrated HCl. Next, it was diluted with 20 ml of deionized water, and was boiled in a water bath till dry. Again, hydration of the remaining ash was carried out with 10 ml of 10% HCl, then, boiled and refluxed for 5 min. The resulting mixture was then filtered into a 10 ml volumetric flask and was made to mark with deionized water. Iron, calcium, and magnesium were determined from standard curves generated from different concentrations of their respective standards using a spectrophotometer, model Jenway 7305 (Bibby Scientific, London, UK) at wavelengths of 422.7, 285.2, and 510.0 nm, respectively. For iron, standard concentrations were 0.00–0.25 mg per 50 ml solution containing 4.0 ml of 10% hydroxylamine hydrochloride and 4.0 ml of 0.3% orthophenanthroline, while for calcium and magnesium, it was 0.00–5.00 ml per 50 ml solution containing 1% wt/vol $LaCl_3$ and 1 N HNO_3. Potassium was measured by flame emission photometer (Sherwood Flame Photometer 410, Sherwood Scientific Ltd, Cambridge, UK) with sodium chloride as a standard.

For phosphorus determination, preparation of test sample and color reaction were carried out following the procedure described by Noureddini et al. (2009). Briefly, zinc oxide (0.5 g) was mixed with dried samples (0.5–1.5 g) using a glass rod in a crucible, ashed at 525°C in a muffle furnace overnight (8 hr) then cooled. Next, after 5 ml each of deionized water and hydrochloric acid had been added, the crucible was covered and boiled for 5 min. This was followed by filtering into a 200 ml volumetric flask and neutralization with 50% KOH. Thereafter, 4–5 drops of 10 M HCl were added and the flask was filled with deionized water. Further dilution of the test sample was carried out by transferring an aliquot (1–10 ml) into an Erlenmeyer flask, diluted to 15 ml with deionized water, and followed with the addition of 20 ml of molybdate-ascorbic acid. Then, the flask was capped and placed in a water bath at 100°C for 15 min, cooled using tap water after which its content, which was now transferred into a 50 ml volumetric flask, was again diluted with deionized water. Absorptions of the test samples were then taken against a blank using a UV spectrophotometer (Thermo Electron Co., 335906 GENE-SYS 10S, Milford, MA) at 823 nm within 1 hr of color reaction. Phosphorus content was calculated thus:

$P\,(\%) = 100 \times \frac{\frac{V2}{V1} \times Pc}{W}$; results were multiplied by 1,000 to convert to mg/100 g.

where V1 = volume (ml) of the solution used in the color reaction, V2 = total volume (ml) of the volumetric flask containing the sample, P_C (mg) = content of phosphorus from a calibration curve corresponding to the absorbance of the sample, and *W* (mg) = weight of dry weight.

Note: Calibration curve was generated from different concentrations (0.00–0.06 mg) of standard phosphorus solutions.

Antinutrients analysis

Trypsin inhibitors and tannins were determined as previously described by Adeleke et al. (2017) while phytates analysis was carried out following the procedure reported by Doss et al. (2011). Method of A.O.A.C (1990) was used for the determination oxalates.

Sensory evaluation

Each of the samples (100 g) was separately added to 1,500 ml of boiling water (100°C) on an electric cooker and was cooked according to previously determined cooking times (Figure 1). The samples were then allowed to cool at ambient temperature before being presented for sensory evaluation, since the panelists indicated preference for ambient temperature. Prior to the sensory evaluation, there was an approval by the Department of Home Economics and Food Science of the study, and the consents of the would-be panelists were sought. They were also screened based on their interest to participate in the sensory evaluation.



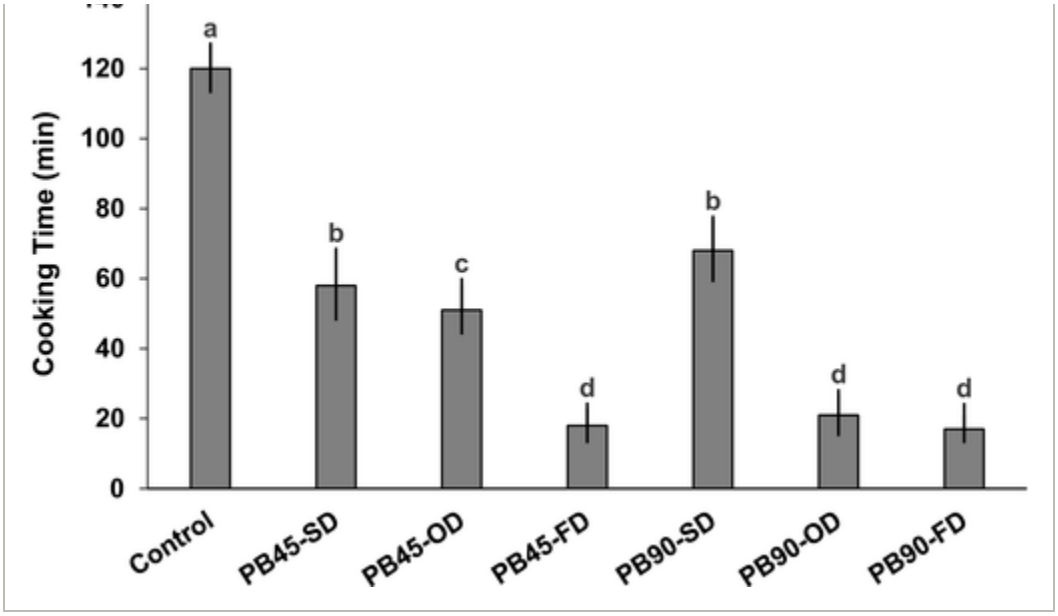


FIGURE 1

Open in figure viewer | PowerPoint

Cooking time of parboiled-dried BGN (PB45 and PB90 represent 45 and 90 min parboiling, respectively, and SD, OD and FD are sun, oven and freeze dried samples, respectively)

Multiple paired comparison test was carried out by using a 50 semi-trained panelists who are familiar with the sensory attributes of boiled BGN, following screening (Akintayo et al., 2019; Arise et al., 2019). The panelists comprised males and females selected from staff (33–49 years) and students (17–25 years) of the Department of Home Economics and Food Science, University of Ilorin, Nigeria. Samples were randomly coded alphanumerically and presented to the panelists under white light for assessment of appearance, aroma, taste, texture, and overall acceptability. A 9-point Hedonic scale of preference, where 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike 6 = like slightly, 7 = like moderately, 8 = like very much, and 9 = like extremely, was used.

Statistical analysis

All the data were subjected to one-way Analysis of Variance (ANOVA) using Statistical Package for Social Sciences (SPSS) version 16.0 (SPSS Inc., Chicago, IL, USA). Means were separated with Duncan Multiple Range of comparison test; and the statistical significance defined was $p \leq .05$.

3 RESULTS AND DISCUSSIONS

Cooking time

Cooking time was significantly ($p \leq .05$) reduced by 43%–86% with pretreatments (combined parboiling and drying) of BGN (Figure 1). Freeze-dried samples required minimum cooking time

of 17–18 min while the control (untreated sample) took 120 min to cook. Denaturation of protein and solubilization of pectin which might have taken place during parboiling may explain the reduction in HTC when compared to the control. This is plausible since protein denaturation is associated with enhanced softening of legumes (Mubaiwa et al., 2017). Similarly, pectate alteration during heating has been reported to influence thermal conductivity and water solubility; this results in easier cell separation during cooking of hardened beans (Mubaiwa et al., 2017).

The reductions in cooking time recorded in the present study were higher than the 20% and 13%, recorded when BGN was cooked with *gowa* and sodium bicarbonate, respectively (Mubaiwa et al., 2019). A recent report by Mubaiwa et al. (2018) showed that Bambara *rupiza,* a product occasionally made in Zimbabwe by dry-roasting of Bambara grits, is characterized with about 45–60 min eventual cooking time. This is comparable with the 22–60 min recorded for sun- and oven-dried samples in this study. Increasing the parboiling time from 45 to 90 min showed significantly reduced cooking time only with oven-dried BGN sample. While the reason for this observation remains yet to be determined, it is suggestive that oven-drying substantially contributed to some of the reactions required for bean softening than did other methods of drying in this study. Though freeze-dried samples demonstrated the lowest cooking time, they did not cook significantly faster than the sample oven-dried following 90 min parboiling (PB90-OD) (Figure 1). Therefore, the latter may be preferred by BGN farmers/processors in order to offer, not just quick-to-cook BGN, but that which is also affordable to the target consumers. Similarly, since the various sundried-parboiled samples recorded significantly shorter cooking time than the control, the method can be adopted for commercial considerations.

Physical properties

3.2.1 Objective color

There was no significant ($p > .05$) difference in the lightness (L^* values) of freeze-dried BGN samples relative to the control (Table 1). On the contrary, sun- and oven-drying resulted in significantly ($p \leq .05$) darker colors. This browning may be explained by the thermal effect associated with sun- and oven-drying as opposed to freeze-drying. This is plausible since BGN contains both carbohydrate and protein, which would respectively provide carbonyl and amino groups required for Maillard reaction. With reference to the control, reduction in lightness was higher in oven-dried (18%–29%) than the sun-dried samples (6%–9%). This may be explained by the higher temperature involved in oven-drying as opposed to sun-drying. Denhere (2016) showed that oven-drying resulted in about 16%–30% decrease in the lightness of the seed testa of two varieties of BGN. Since a^* value indicates redness, the higher values recorded for oven-dried samples can be due to development of more intense brownish color as a result of more

Maillard reaction. Color characteristics of BGN have an influence on consumers' acceptability (Oyeyinka, 2016). For example, the higher *L** and lower *a** values recorded for freeze-dried samples would be desirable for preparation of instant porridge of better consumer acceptance (Denhere, 2016). However, color preferences may depend on the intended final product. With the exception of oven-dried samples, there was no significant difference in the color parameters (*L**, *a**, and *b**) of dried BGN samples with respect to parboiling time. Since the study showed that 90 min parboiling further significantly reduced the *L** value of sundried BGN, 45 min is proposed as a better parboiling option.

TABLE 1. Physical properties of parboiled-dried Bambara groundnut

Properties	Control	45-min Parboiling			90-min Parboiling	
		Sun-dried	Oven-dried	Freeze-dried	Sun-dried	Oven-dri
*L**	$64.19^{a} \pm 2.24$	$60.59^{b} \pm 2.58$	$52.93^{c} \pm 1.94$	$64.86^{a} \pm 1.93$	$58.72^{b} \pm 0.77$	$45.58^{d} \pm$
*a**	$7.04^{ab} \pm 1.69$	$7.44^{ab} \pm 2.34$	$8.51^{ab} \pm 0.65$	$6.55^{ab} \pm 0.29$	$7.91^{ab} \pm 2.67$	$10.26^{a} \pm$
*b**	$24.53^{a} \pm 4.41$	$24.22^{a} \pm 0.93$	$21.91^{a} \pm 1.34$	$23.86^{a} \pm 1.20$	$24.04^{a} \pm 4.30$	$20.54^{a} \pm$
Length (mm)	$10.60^{b} \pm 0.80$	$11.90^{ab} \pm 0.60$	$11.73^{ab} \pm 0.75$	$12.50^{a} \pm 0.70$	$12.23^{ab} \pm 0.45$	$11.70^{ab} \pm$
Width (mm)	$9.50^{a} \pm 0.50$	$9.30^{a} \pm 0.60$	$8.90^{a} \pm 0.75$	$9.40^{a} \pm 0.50$	$8.60^{a} \pm 0.50$	$8.90^{a} \pm$
Thickness (mm)	$9.30^{a} \pm 0.50$	$9.20^{a} \pm 0.40$	$8.80^{a} \pm 0.50$	$9.20^{a} \pm 0.50$	$8.50^{a} \pm 0.50$	$8.63^{a} \pm$
Arithmetic dia. (mm)	$9.80^{a} \pm 0.60$	$10.13^{a} \pm 0.53$	$9.72^{a} \pm 0.54$	$10.37^{a} \pm 0.57$	$9.44^{a} \pm 0.48$	$9.74^{a} \pm$
Geometric dia. (mm)	$9.78^{a} \pm 0.60$	$10.06^{a} \pm 0.53$	$9.65^{a} \pm 0.56$	$10.26^{a} \pm 0.56$	$9.37^{a} \pm 49$	$9.65^{a} \pm$
Sphericity (%)	$0.922^{a} \pm 0.013$	$0.843^{b} \pm 0.001$	$0.839^{bc} \pm 0.023$	$0.819^{cd} \pm 0.001$	$0.832^{bcd} \pm 0.010$	$0.822^{bcd} \pm$
Surface area	$301.55^{a} \pm 36.48$	$318.66^{a} \pm 33.60$	$293.10^{a} \pm 33.62$	$331.69^{a} \pm 36.10$	$276.09^{a} \pm 28.88$	$294.37^{a} \pm$

Note

Values are given as Means ± *SD* (*n* = 3 reps); Means sharing different letters in a row are significantly different from each

other (DMR test, $p \leq .05$).

3.2.2 Linear and other related physical properties

There were significant ($p \leq .05$) variations in the seed length, width and thickness of parboiled-dried BGN when compared with the control (Table 1). The variation recorded could be attributed to the interplay between some changes that took place during pretreatments of the BGN grains, for example, swelling during parboiling and shrinking during drying. However, the values recorded in this study are similar to those reported previously (Mpotokwane et al., 2008; Mubaiwa, 2018). The generally longer lengths of parboiled-dried BGN seeds are consistent with the observation of Adeyanju and Abimbola (2015) who reported that lengths of the seeds increased with cooking. However, these authors reported correspondingly higher width, which is at variance with the results obtained in the present study. The physical properties (length, width, thickness, arithmetic and geometric diameters, sphericity, surface area, and aspect ratio) of all the samples were unaffected ($p > .05$) by variation in parboiling treatment times. Linear characteristics such as length, width, and thickness have been reported to influence particle size and processing operations like sorting and size reduction (Mubaiwa, 2018). Since these parameters significantly differ between the control and the pretreated samples, it may therefore be necessary to also determine their corresponding sorting and milling requirements if results similar to those of the untreated sample are to be achieved. They are also useful in the determination of engineering characteristics including arithmetic/geometric mean diameters and sphericity.

The similarity between the control and parboiled-dried BGN samples in terms of arithmetic and geometric mean diameters (Table 1) imply similarity in the regularity as well as ease of winnowing of the seeds. While arithmetic mean diameter indicates the irregularity of solid shapes (Mubaiwa, 2018), geometric mean diameter represents the ease with which extraneous matter can be removed using pneumatic cleaning (Gharibzahedi et al., 2010; Mubaiwa, 2018). It therefore suggests that the various pretreated samples would well meet consumers' requirements for uniform seed sizes, as well as any subsequent need for particle separation following storage. Though, values recorded in this study are lower than those reported by Adeyanju and Abimbola (2015) for BGN cooked for 1–3 hr, the difference in variety and subsequent drying of parboiled grains in this study could account for this variation. Sphericity and aspect ratio of BGN significantly ($p \leq .05$) reduced in parboiled-dried samples in comparison with the control (Table 1). Sphericity compares a solid shape with a sphere of the same volume while aspect ratio represents its tendency to be oblong in shape (Gharibzahedi et al., 2010). The lower these parameters are, the lower the efficiency of a hopper and a dehulling equipment (Gharibzahedi et al., 2010). With regards to seed sphericity and aspect ratio, data from the study imply that 45 min parboiling followed by sun-drying may be the most

preferred method among the various pretreatment combinations.

Chemical properties

3.3.1 Proximate composition

The moisture contents of the BGN samples ranged between 6.29% and 7.29% (Table 2) which are similar to 6.35%–7.78% previously reported by Anhwange and Atoo (2015). The significantly lower moisture contents of parboiled-dried BGN when compared with the control may be associated with enhanced drying due to prior parboiling. Parboiling presumably caused some tissue rupture which subsequently made moisture removal more efficient. However, prior parboiling of BGN for 90 min before sun- or freeze-drying resulted in higher moisture content than parboiling for 45 min. This suggests that the longer the parboiling time, the higher the amount of water absorbed. Low moisture contents are typical of BGN and have been linked to its relative shelf stability (Anhwange & Atoo, 2015). Thus, samples parboiled for 45 min (irrespective of the drying method) tend to be more shelf-stable than their 90 min parboiled counterparts, as well as the control. The control BGN recorded significantly ($p \leq .05$) lower protein content. This could be attributed to concentration rather than actual increase in amount. This effect is plausible since moisture, fat, and ash contents generally decreased in parboiled-dried samples. The observed increase in protein may also be explained by reduction of antinutrients such as tannins, which typically bind with protein, making it less bio-available. Our values are within the range (15.5%–22.5%) reported in literature (Anhwange & Atoo, 2015; Gulu et al., 2019; Hardy, 2016). The present study suggests that parboiling time does not substantially contribute to leaching or denaturation of proteins of BGN. Having the highest protein content, sample produced from combined 45 min parboiling and oven-drying appears to be the most concentrated in protein.

TABLE 2. Proximate composition (%) of parboiled-dried Bambara groundnut

	Control	45-min Parboiling			90-min Parboiling		
		Sun-dried	Oven-dried	Freeze-dried	Sun-dried	Oven-dried	Fr dr
Moisture	$7.29^{a} \pm 0.01$	$6.29^{d} \pm 0.01$	$6.37^{cd} \pm 0.07$	$6.45^{c} \pm 0.01$	$6.45^{c} \pm 0.01$	$6.44^{c} \pm 0.08$	6
Protein	$17.48^{c} \pm 0.11$	$18.36^{b} \pm 0.15$	$18.63^{a} \pm 0.07$	$18.53^{ab} \pm 0.01$	$18.35^{b} \pm 0.15$	$18.62^{a} \pm 0.08$	18
Fat	$5.90^{a} \pm 0.14$	$5.18^{e} \pm 0.03$	$5.22^{de} \pm 0.03$	$5.38^{c} \pm 0.03$	$5.35^{cd} \pm 0.01$	$5.46^{bc} \pm 0.03$	5
Crude fiber	$4.28^{ab} \pm 0.11$	$4.21^{bc} \pm 0.01$	$4.15^{c} \pm 0.01$	$4.11^{c} \pm 0.01$	$4.33^{a} \pm 0.01$	$4.19^{bc} \pm 0.01$	4
Ash	$3.70^{a} \pm 0.14$	$3.22^{d} \pm 0.03$	$3.38^{bc} \pm 0.03$	$3.39^{bc} \pm 0.01$	$3.26^{cd} \pm 0.03$	$3.44^{b} \pm 0.02$	3

	Control	45-min Parboiling			90-min Parboiling		
		Sun-dried	Oven-dried	Freeze-dried	Sun-dried	Oven-dried	Fr dr
Carbohydrate	61.35^{d} ± 0.07	62.74^{a} ± 0.21	62.25^{b} ± 0.13	62.14^{b} ± 0.03	62.27^{b} ± 0.17	61.85^{c} ± 0.03	6

Note

Values are given as Means ± *SD* (*n* = 3 reps); Means sharing different letters in a row are significantly different from each other (DMR test, $p \leq .05$).

The fat content of the control BGN was significantly ($p \leq .05$) higher than those of the parboiled-dried samples, irrespective of the drying method used. This suggests some loss of fat or fat-like components. A similar observation was reported by Adeyanju and Abimbola (2015) for BGN cooked for 1–3 hr. The authors associated this to cellular rupture and fractionation of intact oil bodies, thus, facilitating aqueous extraction of oil from the seeds. Increasing the parboiling time of BGN seeds from 45 to 90 min significantly ($p \leq .05$) increased the fat content. The continuous breakage in starch–lipid complexes may have rendered more fat available for quantification in the samples. Freeze-dried samples, irrespective of parboiling time, had higher fat content than samples from other methods of drying. The generally low-fat content of BGN indicated its suitability for the formulation of low-fat foods (Oyeleke et al., 2012). The ash contents of parboiled-dried BGN were significantly lower (by about 7%–13%) than that of the control BGN. Leaching of certain minerals during boiling may account for the reduced ash content. The crude fiber contents of 4.11%–4.33% are similar to the range (3.3%–4.5%) reported by Hardy (2016). BGN parboiled for 45 min irrespective of drying methods showed significantly reduced crude fiber, except in sun-dried sample. Boiling has been noted to reduce crude fiber content of some leguminous seeds (Adeyanju & Abimbola, 2015). However, there was a significant increase in crude fiber when parboiling time was increased from 45 to 90 min and subsequently subjected to sun-drying in the present study. While the reason for this requires further investigation, the method seems to be the best pretreatment combination, if BGN of a higher crude-fiber content is desired.

As shown in Table 2, parboiled-dried BGN had higher carbohydrate contents than the control. These values are higher than the range (56.42%–58.13%) reported by Oyeyinka (2016). However, the author also recorded higher moisture contents (8.71%–10.90%) than values (6.29%–7.29%) obtained in this study. Carbohydrate content of BGNs has been reported to range between 56% and 68% (Arise et al., 2019; Oyeyinka et al., 2015). A significant ($p \leq .05$)

decrease in carbohydrate was observed when parboiling was extended from 45 to 90 min, which suggested leaching of some starch and other soluble carbohydrate molecules into the parboiling water. Sun-dried samples showed highest carbohydrate contents.

3.3.2 Mineral composition

Magnesium and potassium were the most predominant minerals in the BGN samples (Table 3). There was a general decrease in the mineral contents, except in iron. Though it may be expected that mineral contents would increase since levels of antinutrients generally reduced (Table 4), simultaneous leaching of the minerals due to prolonged boiling may explain the contrary results obtained. The reduction in mineral contents is consistent with a previous study (Abiodun & Adepeju, 2011) where mineral loss was linked to leaching in boiling water. Calcium and magnesium were the most affected minerals, with 4%–54% and 2%–33% losses, respectively. However, the loss recorded for potassium was relatively lower (0.5%–25%). This suggests that the minerals were bound to other food components at different degrees. This hypothesis is in agreement with the explanation provided by Oyeyinka (2016) that minerals which are more tightly bound within food matrix have higher retention during cooking. The extension in parboiling time enhanced the leaching of most of the minerals but the peculiar increase in iron could be attributed to reduction in its antinutritional factors. While it can be generally postulated that extended parboiling time in this study led to higher loss of minerals, no clearly defined effect of different drying methods could yet be determined. Generally, 45 min parboiling resulted in more retained minerals, with sun-dried BGN being the highest in calcium, freeze-dried sample in potassium and magnesium, while oven-dried sample recorded the highest amount in phosphorus.

TABLE 3. Selected mineral contents (mg/100 g) of parboiled-dried Bambara groundnut

Minerals	Control	45-min Parboiling			90-min Parboiling		
		Sun-dried	Oven-dried	Freeze-dried	Sun-dried	Oven-dried	Free drie
Calcium	$47.29^{a} \pm 0.18$	$45.26^{b} \pm 0.14$	$34.15^{d} \pm 0.07$	$40.03^{c} \pm 0.11$	$23.25^{f} \pm 0.21$	$21.95^{g} \pm 0.14$	25.9
Magnesium	$261.9^{a} \pm 0.32$	$225.9^{d} \pm 0.25$	$253.2^{c} \pm 0.32$	$255.0^{b} \pm 0.57$	$183.3^{f} \pm 0.28$	$175.5^{g} \pm 0.28$	182.
Potassium	$948.1^{a} \pm 2.83$	$931.0^{c} \pm 5.66$	$937.7^{b} \pm 1.06$	$942.9^{a} \pm 2.83$	$710.1^{f} \pm 0.21$	$862.6^{e} \pm 0.71$	757.
Iron	$8.20^{d} \pm 0.14$	$5.80^{f} \pm 2.97$	$4.50^{g} \pm 0.07$	$6.90^{e} \pm 0.11$	$8.90^{c} \pm 0.21$	$9.50^{a} \pm 0.14$	9.10
Phosphorus	$64.29^{a} \pm 1.31$	$49.21^{d} \pm 0.00$	$60.80^{b} \pm 3.89$	$49.75^{c} \pm 2.55$	$46.32^{e} \pm 0.00$	$41.80^{f} \pm 0.42$	48.8

Note

Values are given as Means ± *SD* (*n* = 3 reps); Means sharing different letters in a row are significantly different from each other (DMR test, $p \leq .05$).

TABLE 4. Selected antinutrients (mg/100 g) of parboiled-dried Bambara groundnut

	Control	45-min Parboiling			90-min Parboiling		
		Sun-dried	Oven-dried	Freeze-dried	Sun-dried	Oven-dried	F
Trypsin inhibitors	$10.38^{a} \pm 0.004$	$3.52^{d} \pm 0.009$	$2.48^{f} \pm 0.031$	$6.03^{b} \pm 0.028$	$2.72^{e} \pm 0.012$	$2.28^{f} \pm 0.00$	
Phytates	$338.66^{a} \pm 0.13$	$266.20^{d} \pm 0.14$	$260.95^{e} \pm 0.64$	$274.72^{b} \pm 0.13$	$254.93^{g} \pm 0.45$	$244.02^{f} \pm 0.37$	
Tannins	$0.30^{a} \pm 0.001$	$0.24^{d} \pm 0.000$	$0.22^{e} \pm 0.000$	$0.28^{b} \pm 0.000$	$0.21^{f} \pm 0.007$	$0.19^{g} \pm 0.003$	
Oxalates	$0.58^{a} \pm 0.007$	$0.29^{bc} \pm 0.002$	$0.26^{cd} \pm 0.001$	$0.30^{b} \pm 0.00$	$0.23^{de} \pm 0.035$	$0.20^{e} \pm 0.003$	

Note

Values are given as Means ± *SD* (*n* = 3 reps); Means sharing different letters in a row are significantly different from each other (DMR test, $p \leq .05$).

3.3.3 Antinutrient contents

Generally, the antinutrients in pretreated samples were significantly ($p \leq .05$) lower as compared to those of the raw sample (Table 4). The results also indicate that samples parboiled for 90 min experienced higher decrease in antinutrients than samples parboiled for 45 min, irrespective of the drying methods. This was expected since the samples spent longer time in boiling water, which would allow for more hydrothermal effect on the antinutrients. Ndidi et al. (2014) found boiling of BGN to substantially reduce its level of trypsin inhibitors, oxalates, phytates, and tannins. Similarly, extending the boiling time of BGN from 30 to 60 min has been shown to significantly reduce its antinutritional factors including tannins, phytates, and trypsin inhibitors (Adeleke et al., 2017). Decrease of antinutrients during boiling in water can be explained by the passive diffusion or leaching of water-soluble antinutrients like tannin, and degradation or hydrolysis of others such as phytates (Adeleke et al., 2017). The denaturation of protease inhibitors under the influence of heat (Popova & Mihaylova, 2019)

may also partly explain the reduction of trypsin inhibitors during boiling. Oxalates have likewise been found to be soluble in boiling water (Bhandari & Kawabata, 2006). With regards to method of drying, oven-dried samples recorded the lowest amounts of antinutrients while freeze-dried recorded the highest. This variation can be attributed to difference in drying temperature. The higher temperature employed in oven-drying probably increased the rates of the various reactions leading to reduction of the antinutrients. This is plausible since thermal processing has been linked to the disruption of food matrix and destruction of heat-labile antinutritional factors with consequent release of certain micronutrients and enhanced bioavailability (Akeem et al., 2019).

Findings from this study are similar to some studies reported in literature for pretreated BGN. For example, Adeleke et al. (2017) noted that the trypsin inhibiting activity of raw white BGN decreased from 13.15 TIU/100 g to 8.34 TIU/100 g and 7.88 TIU/100 g when boiled for 30 and 60 min, respectively. Phytates was also reduced from 319.55 mg/100 g to 113.71 mg/100 g when BGN was boiled for 3 hr 48 min (Ndidi et al., 2014). These authors also reported that tannins dropped from 18.61 mg/g (0.1861 mg/100 g) to 5.33 mg/g (0.0533 mg/100 g) while oxalates reduced from 6.15 mg/kg (0.615 mg/100 g) to 1.97 mg/kg (1.97 mg/100 g). Implication of the reductions in antinutrients represents a good indication of improved protein digestibility, increased mineral bioavailability, and reduction of tannin-related hard-to-cook property (Adeleke et al., 2017). In all, the BGN sample pretreated using combined 45 min parboiling and oven-drying was the best in antinutrients.

3.3.4 Sensory properties

There was no significant ($p \leq .05$) difference between the control and freeze-dried BGN samples in terms of appearance (Table 5). This correlates with the appearance of the parboiled-dried grains prior to preparation for sensory evaluation (Figure 2). The characteristic appearance of food material is only minimally impaired by freeze-drying when compared to thermal methods of drying. With respect to aroma, the control and parboiled-dried samples were also similar (approximately 6.0 on a 9-point Hedonic scale), suggesting that the beany aroma of BGN was still equally perceptible. Except for the 90 min parboiled-oven-dried sample, all parboiled-dried samples were similar to the control in texture. This is an indication that the result of the cooking test (Figure 1) used for preparation of samples for sensory evaluation resulted in a similar level of softness.

TABLE 5. Sensory property of parboiled-dried Bambara groundnut (in cooked form)

	Control	45-min Parboiling			90-min Parboiling		
		Sun-dried	Oven-dried	Freeze-dried	Sun-dried	Oven-dried	Freeze dried
Appearance	$6.94^{a} \pm 1.04$	$6.20^{b} \pm 0.97$	$6.04^{b} \pm 1.54$	$6.72^{a} \pm 1.13$	$6.18^{b} \pm 1.44$	$6.08^{b} \pm 1.55$	$6.86^{a} \pm$
Aroma	$6.24^{a} \pm 1.30$	$5.84^{a} \pm 1.25$	$5.80^{a} \pm 1.59$	$6.20^{a} \pm 1.37$	$5.94^{a} \pm 1.33$	$5.78^{a} \pm 1.25$	$6.12^{a} \pm$
Taste	$6.64^{a} \pm 1.01$	$6.28^{ab} \pm 1.13$	$5.94^{b} \pm 1.60$	$6.02^{b} \pm 1.41$	$6.22^{ab} \pm 1.27$	$5.80^{b} \pm 1.40$	$6.30^{ab} \pm$
Texture	$6.48^{a} \pm 1.53$	$6.08^{ab} \pm 1.38$	$5.98^{ab} \pm 1.53$	$6.12^{ab} \pm 1.64$	$6.04^{ab} \pm 1.46$	$5.62^{b} \pm 1.62$	$6.48^{a} \pm$
Overall acceptability	$6.88^{a} \pm 1.04$	$6.42^{abc} \pm 1.14$	$6.34^{bc} \pm 1.38$	$6.70^{ab} \pm 1.22$	$6.28^{bc} \pm 1.23$	$6.10^{c} \pm 1.28$	$6.74^{ab} \pm$

Note

Values are given as Means ± *SD*; Means sharing different letters in a row are significantly different from each other (DMR test, $p \leq .05$).

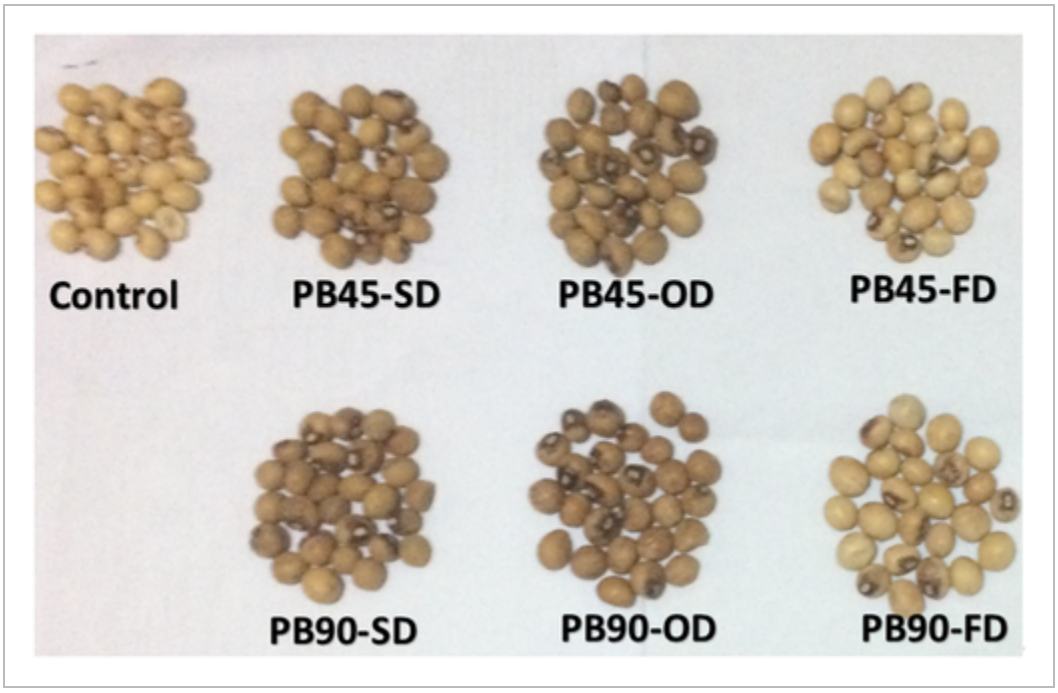


FIGURE 2

Open in figure viewer | PowerPoint

Pictures of parboiled-dried BGN. PB45 and PB90 represent 45 and 90 min parboiling, respectively, and SD, OD and FD are sun-, oven- and freeze-dried samples, respectively

While freeze-dried samples were the most acceptable in sensory quality among the pretreated samples, oven-dried samples generally recorded lower scores. This may be due to higher intensity of heat used in oven-drying than in other methods of drying. Higher degree of browning may account for the impairment of vital sensory properties such as flavor and appearance. For overall acceptability, freeze-dried samples (6.70–6.74) and sample sun-dried after 45 min of parboiling (6.42) were not rated significantly different from the control (6.88). Therefore, combined 45 min parboiling and sun-drying is an effective method to be employed, since it produced BGN sample with a comparable overall acceptability with the control. Even though other samples had significantly lower overall acceptability than the control, they were still generally accepted by the panelists (6.10–6.34). Extending the parboiling time from 45 to 90 min, however, showed no significant effect on the sensory characteristics of the BGN seeds samples.

4 CONCLUSIONS

The study revealed a viable preprocessing strategy that can be employed by farmers and food industries to address the hard-to-cook phenomenon of BGN. Cooking time was markedly reduced through combined parboiling and drying. The light color of the seeds was substantially retained in freeze-dried samples but the study showed that sun- and oven-dried samples would become noticeably brown with prolonged parboiling. Minimal changes in the physical properties of the seeds indicate minor effect on processing operations such as dehulling. Protein contents were more concentrated while other proximate components, except carbohydrate, reduced following preprocessing operations employed. Combined parboiling and drying markedly reduced the antinutrients in BGN. Parboiled-dried BGN cooked samples compared well with the control, with freeze-drying having highest consumer preference among the drying methods. From commercial point of view and final cooking time, both sun- and oven-drying methods are proposed for application. Particularly, 45 min parboiling of BGN followed by sun-drying may be recommended for adoption by BGN farmers/processors. First of all, since it is relatively cheaper and practicable, it can be offered at an affordable price to consumers. Again, BGN pretreated using this method maintained panelists' overall acceptability similar to that of the control. Further studies are recommended to investigate the storage potential of parboiled-dried BGN.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTION

Olaide Akinwunmi Akintayo: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Supervision; Visualization; Writing-original draft; Writing-review & editing. **Kikelomo Elizabeth Adegbaju:** Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Resources; Writing-original draft. **Sarafa Adeyemi Akeem:** Conceptualization; Resources; Writing-original draft; Writing-review & editing. **Mutiat Adebanke Balogun:** Supervision; Validation; Writing-review & editing. **Olabanji Jamiu Adediran:** Project administration; Validation; Writing-review & editing. **Tawakalitu Eniola Aruna:** Visualization; Writing-review & editing. **Fadilat Modupeola Akintayo:** Writing-original draft; Writing-review & editing. **Boluwatife Adesina:** Data curation; Methodology. **Happiness Obiageri Onwudinjo:** Project administration; Resources. **Peter Korede Ojo:** Resources; Writing-review & editing. **Fausat Kolawole:** Writing-review & editing.

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DATA AVAILABILITY STATEMENT

Data available on request from the authors.

REFERENCES

A.O.A.C. (1990). *Official methods of analysis of the AOAC international* (15th ed.). Washington, DC: The Association of Official Analytical Chemists.

A.O.A.C. (2000). *Official methods of analysis of AOAC international* (16th ed.). Gaithersburg, MD: The Association of Official Analytical Chemists.

Abiodun, A., & Adepeju, A. (2011). Effect of processing on the chemical, pasting and anti-nutritional composition of Bambara nut (*Vigna subterranea* L. Verdc) flour. *Advance Journal of Food Science and Technology*, **3**, 224– 227.

Adeleke, O., Adiamo, O. Q., Fawale, O. S., & Olamiti, G. (2017). Effect of soaking and boiling on anti-nutritional factors, oligosaccharide contents and protein digestibility of newly developed Bambara groundnut cultivars. *Turkish Journal of Agriculture-Food Science and Technology*, **5**(9), 1006– 1014. https://doi.org/10.24925/turjaf.v5i9.1006-1014.949

Adeyanju, J. A., & Abimbola, A. O. (2015). Some engineering and chemical properties of cooked Bambara groundnut. *Donnish Journal of Food Science and Technology*, **1**, 22– 26.

Akeem, S. A., Kolawole, F. L., Joseph, J. K., Kayode, R. M. O., & Akintayo, O. A. (2019). Traditional food processing techniques and micronutrients bioavailability of plant and plant-based foods: A review. *Annals. Food Science and Technology*, **20**(1), 30– 41.

Akintayo, O. A., Obadu, J. M., Karim, O. R., Balogun, M. A., Kolawole, F. L., & Oyeyinka, S. A. (2019). Effect of replacement of cassava starch with sweet potato starch on the functional, pasting and sensory properties of tapioca grits. *LWT – Food Science and Technology*, **111**, 513– 519. https://doi.org/10.1016/j.lwt.2019.05.022

Anhwange, B., & Atoo, G. (2015). Proximate composition of indigenous Bambara nuts (*Vigna subterranean* (L.) Verdc). *SCSR Journal of Pure and Applied Sciences*, **2**, 11– 16.

Arise, A., Akintayo, O., Dauda, A., & Adeleke, B. (2019). Chemical, functional and sensory qualities of abari (maize-based pudding) nutritionally improved with Bambara groundnut (*Vigna subterranea*). *Ife Journal of Science*, **21**, 165– 173. https://doi.org/10.4314/ijs.v21i1.14

Aviara, N., Lawal, A., Atiku, A., & Haque, M. (2013). Bambara groundnut processing, storage and utilization in north eastern Nigeria. *Continental Journal of Engineering Science*, **8**, 28– 36.

https://doi.org/10.5707/cjengsci.2013.8.1.28.36

Bhandari, M. R., & Kawabata, J. (2006). Cooking effects on oxalate, phytate, trypsin and α-amylase inhibitors of wild yam tubers of Nepal. *Journal of Food Composition and Analysis*, **19**(6–7), 524– 530. https://doi.org/10.1016/j.jfca.2004.09.010

Denhere, S. (2016). *The effect of adding Bambara groundnut (Vignia substerranea L.) on the nutritional, functional and sensory quality of a provitamin α-biofortified maize complementary instant porridge (Master's dissertation)*. University of KwaZulu-Natal.

dos Santos Siqueira, B., Vianello, R. P., Fernandes, K. F., & Bassinello, P. Z. (2013). Hardness of carioca beans (*Phaseolus vulgaris* L.) as affected by cooking methods. *LWT - Food Science and Technology*, **54**(1), 13– 17.

Doss, A., Pugalenthi, M., Vadivel, V., Subhashini, G., & Subash, A. R. (2011). Effects of processing technique on the nutritional composition and antinutrients content of under–utilized food legume *Canavalia ensiformis* L. DC. *International Food Research Journal*, **18**(3), 965– 970.

Effa, E. B., & Uko, A. (2017). Food security potentials of Bambara groundnut (*Vigna subterranea* L. Verdc.). *International Journal of Development and Sustainability*, **6**, 1919– 1930.

Emmanuel, O., Clement, A., Agnes, S., Chiwona-Karltun, L., & Drinah, B. (2012). Chemical composition and cyanogenic potential of traditional and high yielding CMD resistant cassava (*Manihot esculenta* Crantz) varieties. *International Food Research Journal*, **19**, 175– 181.

Gharibzahedi, S., Etemad, V., Mirarab-Razi, J., & Fos hat, M. (2010). Study on some engineering attributes of pine nut (*Pinus pinea*) to the design of processing equipment. *Research in Agricultural Engineering*, **56**, 99– 106. https://doi.org/10.17221/49/2009-RAE

Gulu, N. B., Jideani, V. A., & Jacobs, A. (2019). Functional characteristics of Bambara groundnut starch-catechin complex formed using cyclodextrins as initiators. *Heliyon*, **5**, e01562. https://doi.org/10.1016/j.heliyon.2019.e01562

Hardy, Z. (2016). *Functional and nutritional characteristics of Bambara groundnut milk powder as an ingredient in yoghurt* (Masters thesis). Cape Peninsula University of Technology.

Mpotokwane, S., Gaditlhatlhelwe, E., Sebaka, A., & Jideani, V. (2008). Physical properties of Bambara groundnuts from Botswana. *Journal of Food Engineering*, **89**, 93– 98. https://doi.org/10.1016/j.jfoodeng.2008.04.006

Mubaiwa, J. (2018). *Managing the hard-to-cook (HTC) phenomenon in Bambara groundnut (Vigna subterranea (L.) Verdc.) processing for resource limited communities in Zimbabwe* (Doctoral thesis). Wageningen University, Netherlands.

Mubaiwa, J., Fogliano, V., Chidewe, C., Bakker, E. J., & Linnemann, A. R. (2018). Utilization of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) for sustainable food and nutrition security in semi-arid regions of Zimbabwe. *PLoS ONE*, **13**, e0204817. https://doi.org/10.1371/journal.pone.0204817

Mubaiwa, J., Fogliano, V., Chidewe, C., & Linnemann, A. R. (2017). Hard-to-cook phenomenon in Bambara groundnut (*Vigna subterranea* (L.) Verdc.) processing: Options to improve its role in providing food security. *Food Reviews International*, **33**, 167– 194. https://doi.org/10.1080/87559129.2016.1149864

Mubaiwa, J., Fogliano, V., Chidewe, C., & Linnemann, A. R. (2019). Influence of alkaline salt cooking on solubilisation of phenolic compounds of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) in relation to cooking time reduction. *LWT - Food Science and Technology*, **107**, 49– 55. https://doi.org/10.1016/j.lwt.2019.02.067

Murevanhema, Y. Y., & Jideani, V. A. (2013). Potential of Bambara groundnut (*Vigna subterranea* (L.)

Verdc) milk as a probiotic beverage—A review. *Critical Reviews in Food Science and Nutrition*, **53**, 954–967. https://doi.org/10.1080/10408398.2011.574803

Ndidi, U. S., Ndidi, C. U., Aimola, I. A., Bassa, O. Y., Mankilik, M., & Adamu, Z. (2014). Effects of processing (boiling and roasting) on the nutritional and antinutritional properties of Bambara groundnuts (*Vigna subterranea* [L.] Verdc.) from Southern Kaduna, Nigeria. *Journal of Food Processing*, **2014**, 9 pages.

Neha, P., Anita, R., & Vineet, K. (2017). Effect of processing and dehulling on cooking quality of selected soybean variety. *International Journal of Advances in Science Engineering and Technology*, **5**(1), 82– 84.

Noureddini, H., Malik, M., Byun, J., & Ankeny, A. (2009). Distribution of phosphorus compounds in corn processing. *Bioresource Technology*, **100**(2), 731– 736. https://doi.org/10.1016/j.biortech.2008.05.056

Ojimelukwe, P. C. (1999). Cooking characteristics of four cultivars of Bambara groundnuts seeds and starch isolate. *Journal of Food Biochemistry*, **23**, 109– 117. https://doi.org/10.1111/j.1745-4514.1999.tb00008.x

Oyeleke, G., Afolabi, O., & Isola, A. (2012). Some quality characteristics and carbohydrate fractions of Bambara groundnut (*Vigna subterranea* L.) seed flour. *IOSR Journal of Applied Chemistry*, **2**(4), 16– 19. https://doi.org/10.9790/5736-0241619

Oyeyinka, A. T. (2016). *Nutritional, sensory and functional properties of a Bambara groundnut complimentary food* (Doctorate thesis). University of KwaZulu-Natal.

Oyeyinka, S. A., Singh, S., Adebola, P. O., Gerrano, A. S., & Amonsou, E. O. (2015). Physicochemical properties of starches with variable amylose contents extracted from Bambara groundnut genotypes. *Carbohydrate Polymers*, **133**, 171– 178. https://doi.org/10.1016/j.carbpol.2015.06.100

Popova, A., & Mihaylova, D. (2019). Antinutrients in plant-based foods: A review. *The Open Biotechnology Journal*, **13**(1), 68– 76. https://doi.org/10.2174/1874070701913010068

Schoeninger, V., Coelho, S. R. M., Christ, D., & Sampaio, S. C. (2014). Processing parameter optimization for obtaining dry beans with reduced cooking time. *LWT - Food Science and Technology*, **56**(1), 49– 57. https://doi.org/10.1016/j.lwt.2013.11.007

Subuola, F., Widodo, Y., & Kehinde, T. (2012). Processing and utilization of legumes in the tropics. In A. A. Eissa (Ed.), *Trends in vital food and control engineering* (pp. 71– 85). Janeza Trdine. https://doi.org/10.5772/36496

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