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To cite this article: Bennett Dzandu, Evans Tettey & Michael Bruce-Adjei (2025) Physico-chemical and functional properties of unripe plantain and Bambara groundnut flour blends for doughnut production, Cogent Food & Agriculture, 11:1, 2420470, DOI: [10.1080/23311932.2024.2420470](https://doi.org/10.1080/23311932.2024.2420470)

To link to this article: <https://doi.org/10.1080/23311932.2024.2420470>



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Published online: 28 Dec 2024.



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Physico-chemical and functional properties of unripe plantain and Bambara groundnut flour blends for doughnut production

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ABSTRACT

This study evaluated the quality characteristics of doughnuts made from blend of plantain (PF) and Bambara groundnut (BGF). Four blends specifically PF90%:BGF10%, PF85%:BGF15%, PF80%:BGF20% and PF75%:BGF25% were formulated. Their composition and functional properties as well as attributes of the doughnuts were evaluated. Also, the sensory acceptability of the doughnuts was evaluated. Moisture and fat content of the blends was less than 6% and 4%, respectively, ash content was up to 2.31% and carbohydrates ranged from 69.50 to 92.12%. BGF recorded the highest protein value of 20.35%. The highest bulk density reported was 0.98 g/ml. Water absorption capacity ranged from 50.81 to 66.43% at 27°C and 51.20 to 76.53% at 70°C. The average oil absorption capacity was 49.24%. Emulsion capacity and stability were affected by the amount of BGF. Microbial analysis showed that the doughnuts were safe to eat. The overall sensory scores for the doughnuts ranged from 5.79 to 7.10. Likewise, the doughnuts were acceptable to consumers with an average rating of 7 out of 9. The results of this study show that the Bambara groundnut-plantain blend is suitable for baked goods such as doughnuts and can also be used as an ingredient in various food formulations, especially gluten-free products.

ARTICLE HISTORY

Received 22 December 2022
Revised 21 October 2023
Accepted 18 October 2024

KEYWORDS

Doughnuts; plantain;
Bambara groundnuts;
sensory; flour

SUBJECTS

Nutraceuticals &
Functional Foods; Food
Analysis



1. Introduction

Plantain, as it is commonly called, belongs to the family of plants known as the *Musaceae* (Uzoukwu et al., 2015). Scientifically, it is referred to as *Musa plantaginaceae* (Anajekwu et al., 2020). Historically, plantain is believed to have originated from Southeast Asia and later introduced to Africa, and grown in African countries such as; Uganda, Ghana, Nigeria, Cote d'Ivoire, Cameroon, among others (The Plantain Council, 2018). Nigeria is the largest plantain producing country in Africa and one of the largest in the world. Nigeria produces more than 2.11 million metric tonnes of plantains annually (Anajekwu et al., 2020). In Ghana, about 2.0 million tonnes of plantains are produced yearly (Dankyi et al., 2006).

Plantain is a staple starchy food that provides a high-calorie energy source in the West African Sub-region (Dankyi et al., 2006). Plantain is rich in nutrient such as vitamins, minerals, good source of fibre, vitamins A, C and B-6 as well as magnesium,

and potassium (Cafasso, 2019). Cafasso (2019) explained that the fibre present in plantain aids in promoting bowel function, manage weight and also possesses antioxidant properties. Socio-economically, plantains serve as a source of income, especially in Ghana, where plantains are sold in various local markets. Reports indicated that it created about 265,785 direct and permanent jobs in Ghana, and some are exported for foreign exchange (Dankyi et al., 2006). In Ghana, some plantain recipes include; boiling the plantain and eating it with *Kontomire* stew, boiling and pounding it with boiled cassava to prepare *fufu* and fried and eating it with boiled beans and as fried plantain chips, among others.

Plantain flour is a major product obtained from plantains. Research conducted by Adegunwa et al. (2017), showed that plantain flour has good functional properties and so can be used as a functional agent in bakery products due to the fact that it has a high water absorption capacity (WAC). Bambara

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groundnut (*Vigna subterranea*) is a legume that is locally and widely grown in Africa. Nutritionally, it contains high amount of protein (9.60 to 40.0%) (Adebayo-Oyetoro et al., 2017). The amino acids present in Bambara groundnut are well balanced, thus rendering it suitable for enriching other food products with low amounts of protein (Nwadi et al. (2020). Bambara groundnuts have been utilized in the production of vegetable milk, low-fat yoghurt; value added snacks, and a puree for infant feeding (Nwadi et al., 2020). It is also inexpensive and easy to transport, thus making it a good source of protein for people living in developing countries (Yusufu & Ejeh, 2018). Hence, flour produced from Bambara groundnut can be used an ingredient in the enrichment of plantain flour to formulate food products such as doughnuts. Bryk (2021) described a doughnut is a fried sweet dough that is ring or globule in shape and is either leavened with yeast or other chemical agents. A doughnut can also be baked, and the baked one, has fewer calories than the fried one making it healthier (Stafford, 2021). Doughnuts are made at home, produced and sold by small private bakeries and large processing companies as well (Bryk, 2021). The ingredients needed when producing doughnuts include, flour, baking powder, eggs, milk, and flavorings (Stafford, 2021). Doughnuts are fried and contains sugar, as well as other flavorings and toppings that contribute to the amount of fat and sugar in them, and so may pose certain health risks such as being overweight, obese, diabetic or cancer (Picincu, 2018). Therefore, using formulations of flour containing different types of nutrients and baking it instead of frying it will reduce these risks, making doughnut a healthy snack to enjoy (Yusufu & Ejeh, 2018).

The Quality assessment of flour and food samples includes measuring certain properties of the flour, such as, its functional and proximate composition. Functional properties of food are related to the behavior of food ingredients during processing and how they affect the finished product in terms of how it looks, tastes and feels in the mouth (Devi & Khatkar, 2016). The composition and properties of a particular food determines its functional properties (Gani & Ashwar, 2021). Some constituents of food, such as carbohydrates, proteins and fats constantly interact within the food matrix to bring about such functionalities (Kouakou et al., 2013). Examples of functional properties of food include swelling capacity, bulk density, oil absorption capacity, water absorption capacity, foaming capacity and stability,

gelation and emulsion activity and stability. Proximate analysis of food involves the determination of the major components of food, including moisture, ash, fat, protein and carbohydrate (Nielson, 2010). Some other analyses, including pH, texture, weight, thickness, and diameter and color determination of baked products are considered ways in which the quality of food products is assessed.

Plantain flour alone cannot meet one's protein requirements thus, fortification is essential to ensure that products obtained from plantain flour are nutritionally balanced (Adegunwa et al. (2017). The use of plantain and Bambara groundnut flour to formulate a food product for public consumption is very limited and so many people rely on wheat and other flour products to produce bread, cake and other confectionaries. Therefore, this study evaluated the properties of plantain and Bambara groundnut flour blends as ingredients for formulations of baked products such as doughnuts. Plantain and Bambara groundnut flour blends were evaluated for their functional properties, proximate composition and quality characteristics. In addition, quality characteristics, including microbial one, of doughnuts produced from the flour blends were determine. A sensory evaluation was also conducted to determine the acceptability of the doughnuts produced. Ultimately, this will expand their utilization by encouraging the use of plantain and Bambara groundnut flour to produce other foods. Also, it can help to limit the importation of cereal flours such as wheat flour and possibly reduce the cost of production for bakery products in relation to ingredients of which flour contributes the largest portion.

2. Materials and methods

2.1. Source of raw materials

The unripe plantain and the Bambara groundnut were purchased from Dansoman and Madina markets, in Accra, Ghana.

2.2. Processing of plantain and Bambara groundnut flour

The production for the processing of unripe plantain flour was done by following the method of Adegunwa et al. (2017) with slight modification. Water blanching at 80 °C for 5mins was done to prevent browning of the plantain instead of the use of NaHSO₃ as described in the method by Adegunwa et al. (2017).

The procedure for the processing of the Bambara groundnut flour was followed as described by Yusufu and Ekeh (2018) with a modifications. The processes for the production of plantain and Bambara groundnut flour are shown in Figures 1 and 2.

2.3. Formulation of flour blends

Plantain flour was fortified with Bambara groundnut flour from 10% to 25%. The samples were mixed thoroughly and packaged in plastic containers for storage at temperature of 5°C until further analysis and doughnut production. One hundred percent (100%) plantain and Bambara groundnut flour were used as control (Table 1).

2.4. Proximate composition of flour

2.4.1. Moisture

Moisture content was determined according to American Association of Cereal Chemists (AACC) (1999). Five grams (5g) of sample was weighed into a pre-weighed can and dried in an air oven at a temperature of 105°C for 6h. The grams of moisture removed from the sample were calculated by subtracting the weight of the empty can from the weight of the can plus the dehydrated sample. Percent moisture was calculated as follows:

$$\% \text{ Moisture} = \frac{\text{Weight of moisture removed}}{\text{Weight of sample}} \times 100$$

2.4.2. Protein content

The protein content of the sample was determined according to the method described by Jannathulla et al. (2020). It was estimated by measuring the nitrogen content in the flour using the Kjeldahl method. The nitrogen content was multiplied by a factor of 6.25 to obtain the percent protein. The result was reported as g/100g of sample. That is, Protein (%) = Nitrogen content x 6.25.

2.4.3. Fat content

The Soxhlet method was used for fat extraction from the flours. The procedure was followed as stated by Strungnell (1989). Two grams (2g) of the sample was weighed and transferred into thimbles and extracted with petroleum ether using a Soxhlet. After about 4h of extraction process, extracted fat in a flask was dried in an air oven for 2 hours at 60°C and the fat recovered was weighed. The fat was calculated as follows:

$$\text{Fat (\%)} = \frac{\text{Weight of fat}}{\text{Weight of sample}} \times 100$$

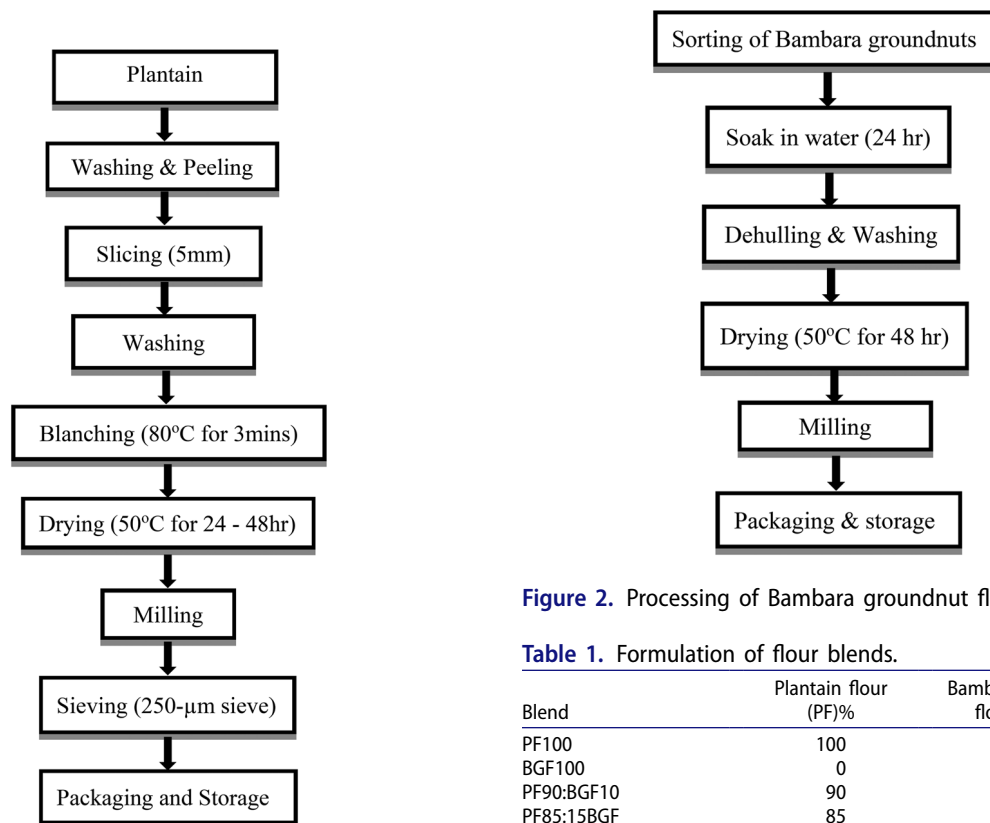


Figure 1. Processing of unripe plantain flour.

Figure 2. Processing of Bambara groundnut flour.

Table 1. Formulation of flour blends.

Blend	Plantain flour (PF)%	Bambara groundnut flour BGF (%)
PF100	100	0
BGF100	0	100
PF90:BGF10	90	10
PF85:15BGF	85	15
PF80:BGF20	80	20
PF75:BGF25	75	25

2.4.4. Ash content

The ash content was determined using AACC (1999) method 08–03.01. Five grams (5g) of the flour samples were measured into ash dishes (crucibles). The samples were placed in a muffle furnace at 600°C. They were incinerated until light gray ash or a constant weight was obtained (12h). After cooling, the samples were weighed, and the ash contents were calculated as follows:

$$\text{Ash (\%)} = \frac{\text{Weight of the ash}}{\text{Weight of original sample}} \times 100$$

2.4.5. Carbohydrate

The carbohydrate content was calculated by subtracting all the other components determined from 100. % Carbohydrate = 100 – (% moisture + % protein + % fat + % ash).

2.5. Functional properties of flour

2.5.1. Bulk density (BD)

The procedure for determination of bulk density was followed as described by Ashraf et al. (2012); however, 20g of the flour samples were used instead of 10g. Twenty grams (20g) of the flour sample was measured into a 50ml graduated cylinder and lightly tapped on the work bench several times until a constant height was attained. The bulk density was then calculated and expressed in grams per milliliter.

$$\text{Bulk density} = \frac{\text{Weight of sample (g)}}{\text{Volume of sample (ml)}}$$

2.5.2. Oil absorption capacity (OAC)

The procedure described by Niba et al. (2002) was followed. Two grams (2g) of each sample was suspended in 10ml of soybean oil in a centrifugal tube, after which the slurry was shaken on a platform tube rocker for 1 minute at room temperature and centrifuged at 300rpm for 15 min. The supernatant was decanted and discarded. The adhering drops of oil were removed and reweighed. OAC was calculated as follows:

$$\text{OAC} = \frac{\text{Weight of sample} - \text{Weight of oil absorbed}}{\text{Weight of sample}} \times 100$$

2.5.3. Water absorption capacity (WAC)

The water absorption capacity of the flour samples was determined following the method described by

Sosulski et al. (1976) with few modifications. Five grams (5g) of each sample were weighed into a centrifuge tube. Thirty milliliters (30ml) of distilled water at 27°C was added and thoroughly mixed. It was left to stand for 30min and stirred after every 10 minutes. It was centrifuged at 3000 x g for 15 minutes. The supernatant was decanted and the residue weighed. The amount of water retained in the sample was calculated. The procedure was repeated using water at 70°C. WAC was calculated as:

$$\text{WAC} = \frac{\text{Weight of sample} - \text{Weight of water retained in sample}}{\text{Weight of sample}} \times 100$$

2.5.4. Foaming capacity (FC) and stability (FS)

Foaming capacity (FC) and foaming stability (FS) were determined to the method as described by Narayana and Narasinga Rao (1982) with slight modification. The initial volume was recorded after two grams (2g) of the sample were weighed into 50ml distilled water at 30±2°C in a 100ml measuring cylinder. The sample was transferred into a food blender and blended for 30seconds to foam. The sample was transferred back into the measuring cylinder and the final volume with foam on top was noted. FC was calculated as follows:

$$\text{FC} = \frac{\text{Volume of mixture after blending} - \text{Volume of mixture before blending}}{\text{Volume of mixture after blending}} \times 100$$

The mixture was left to stand for 30mins and the volume of mixture recorded. FS was calculated as follows:

$$\text{FS} = \frac{\text{Volume of mixture before blending} - \text{Volume of mixture after 30mins}}{\text{Volume of mixture before blending}} \times 100$$

2.5.5. Emulsion capacity (EC) and stability (ES)

Emulsion activity and stability were determined following the method described by Yasumatsu et al. (1972). An emulsion of 1g of flour sample, 10mL distilled water and 10mL vegetable oil was prepared in a calibrated centrifuge tube. The emulsion was subjected to centrifugation at 3000 x g for 5min. The emulsion capacity was calculated as the ratio of the emulsion layer's height to that of the mixture and multiplied by 100. To determine the emulsion stability, the emulsion was then heated at 80°C for 30min in a water-bath, and cooled for 15mins under running tap water. It was

then centrifuged at 3000 x g for 15 min. The emulsion stability was estimated as the ratio of the height of the emulsified layer to the total height of the mixture.

2.5.6. Color

The color of the flour samples was determined using a colorimeter (CR-400 Chroma Meter, Minolta, Japan). The colorimeter was first calibrated according to the manufacturer's instructions. Sample of each of the flours was prepared in a petri dish ensuring that the flour covers the bottom of the petri dish completely. The colorimeter was held over the sample and shots was taken 3 times at the right, middle and left portions of the sample in the petri dish. The values displayed were recorded and an average was taken. Color coordinate values L^* (lightness), a^* (redness) and b^* (yellowness), redness and the overall color (ΔE) of the flour formations were determined.

2.5.7. pH

The pH of the sample was determined using a pH meter. The pH meter was standardized with buffer solutions of pH 4.0 and 7.0, respectively. Ten grams (10g) of sample was dissolved in 100ml distilled water in a beaker and allowed to settle at room temperature for 30mins to dissolve. The tip of the pH meter was cleaned and dipped into the mixture for a while until the reading was stable and the value recorded.

2.6. Production of doughnuts

The ingredients used for making the doughnuts are listed in Table 2. About 450 grams of margarine

and 100 grams of sugar were creamed together in a clean medium bowl until it is creamy. Ten (10) large size eggs were added to the mixture while creaming. Milk (100 ml) was added, a tablespoon of baking powder (10 grams) and vanilla butter flavor (10ml) were added to the mixture while creaming (stirring) the mixture until it was homogenous. The doughnut baker (Geepas Electronic Doughnut Baker, model number GDM2036) was preheated to a temperature of 180°C. A scoop of doughnut mixture was placed in the ring-like holes of the doughnut baker and left for 5mins to fully bake. The doughnuts were allowed to cool and packaged (Figure 3).

2.7. Assessment of doughnuts

2.7.1. Net weight of doughnuts

A digital weighing scale was used to measure the weight of doughnuts. A clean paper plate was placed on the scale and tarred. The doughnut was placed on the plate and the weight was recorded. The procedure was repeated for 5 different doughnuts of each sample and an average was taken for each type of doughnut.

Table 2. Ingredients for doughnut.

Ingredient	Quantity/amount
Sugar	100 grams
Milk	100 ml
Flour blend	450 grams
Margarine	450 grams
Vanilla essence	1 tablespoon (10 ml)
Baking powder	1 leveled tablespoon (10 grams)
Eggs	10 large size



Figure 3. Packaged doughnut produced from plantain and Bambara groundnut flour blend.

2.7.2. Thickness and diameter of doughnut

The thickness and diameter of the five (5) different doughnuts made from each formulated flour samples were measured with a ruler, and an average thickness and diameter were calculated. The measurements were taken in centimeters and converted to inches.

2.7.3. pH of doughnuts

Doughnuts were mashed and mixed in 100ml distilled water and allowed to stand for 30 minutes. The pH meter already standardized with buffer solutions of pH 4.0 and 7.0, was used to measure the pH. The probe of the pH meter was cleaned and dipped into the mixture for a while until the reading was stable and the value was recorded.

2.7.4. Color of doughnuts

The color of each doughnut sample was determined using a colorimeter (CR-400 Chroma meter, Minolta, Japan) which was first calibrated according to the manufacturer's instructions. Enough doughnuts were placed in a petri dish ensuring that it covers the bottom of the petri dish completely. The colorimeter was held over the sample and shots were taken 3 times at the right, middle and left portions of the sample in the petri dish. The values displayed were recorded and an average was taken. Color coordinate values L^* (lightness), a^* (redness) and b^* (yellowness), redness and the overall color (ΔE) were measured and recorded.

2.7.5. Textural analysis of doughnuts

The procedure for texture analysis of doughnuts was followed as described by Sirichokworrakit et al. (2016) with a few modifications. A compression test was performed on the doughnuts using a Texture Analyzer (Stable Micro Systems Texture Analyzer, TA-XT plus model). A TA-30 (3" diameter and 10cm tall) flat probe was attached. The distance between the probe and the stage was set at 10cm. A maximum force of 50N was applied to imitate the chewing action of the teeth. The doughnut samples were compressed up to 50% of their original height at a test speed of 1.0mm/s. The texture parameter analyzed was hardness. The values were reported as means \pm standard deviations in grams force (gf).

2.8. Microbial quality of doughnuts

2.8.1. Preparation of media

The method for media preparation was followed as indicated (on the label) by the manufacturer of each

media or agar. For the plate count agar (PCA), 2.25g was weighed and 100ml distilled water was added. For the potato dextrose agar (PDA), 3.90g of the agar was weighed and 100ml distilled water was added. For the violet red bile glucose agar (VRBGA), 7.02g of agar was weighed and 100ml distilled water was added to it. For the nutrient broth, 7.02g of agar was weighed and 540ml distilled water was added to it. All the mixtures, including the petri dishes were autoclaved for 15 mins at 121°C and the media/agars were maintained at 45–50°C in a water bath until use.

2.8.2. Sample preparation

Ten grams (10g) of each sample of doughnut were weighed into an aseptically labeled stomacher bag. About ninety milliliters (90ml) of nutrient broth was added to each of the samples in the stomacher bag and homogenized.

2.8.3. Microbial load of doughnuts

The pour plate method, as described by Aryal (2019), was used. One milliliter (1ml) of homogenized sample was aseptically pipetted into labeled petri dishes. For each test, fifteen milliliters (15ml) of the appropriate medium or agar was poured into the petri dishes containing the inoculum and thoroughly mixed by swirling it on the working bench in alternate rotation. They were then allowed to solidify and incubate at 37°C in an inverted position. The total plate count (PCA) and Total coliforms (VRBCA) were observed for growth in the next 24h while Yeast and Mold (PCA) dishes were observed in 72h for growth.

2.9. Sensory evaluation of doughnuts

A consumer sensory test was carried out to assess the acceptability of the doughnuts. Eighty (80) untrained panelists were recruited using a recruitment questionnaire from the University of Ghana and others were recruited within the city of Accra, Ghana. The participants included 42 (52.5%) males and 38 (47.5%) females. Sixty-seven (67) of the participants were between the ages of 18–24, 19 were between the ages of 24–34 and 1 person was between the ages of 45–54. The majority of the participants were students and others were government and private workers while others were self-employed. The nine-point hedonic scale was used where 9=like extremely, 8=like very much, 7=like moderately, 6=like slightly, 5=neither like

nor dislike, 4=dislike slightly, 3=dislike moderately, 2=dislike very much and 1=dislike extremely. The sensory characteristics that were evaluated included appearance, color, aroma, taste, mouth-feel, texture and overall liking. Also, participants commented on what they liked or disliked about each sample. The samples were presented to the panelists on paper plates lined with tissue paper with a fork and water in a disposable cup. The samples were presented to the panelists' one after the other. Each panelist tasted 6 different samples. The sensory test was completed within 3 days and the scores for the various attributes evaluated by the panelists were compiled. The sensory test was conducted at the Sensory Laboratory of the Department of Nutrition and Food Science, University of Ghana. Approval for the sensory study (ECBAS 048/15–16) was obtained from the Ethics committee of the College of Basic and Applied Sciences, University of Ghana.

2.10. Data analysis

The Microsoft Excel Professional Plus 2010 program was used to calculate means and standard deviations as well as graphs. Minitab 2017 and 2019 versions were used to run ANOVA test to compare the means whether or not they differ significantly using Tukey's HSD test at a significance level of $\alpha=0.05$ and confidence interval of 95%.

3. Results and discussion

3.1. Proximate composition of flour blends

3.1.1. Moisture

The moisture content of the flours ranged from $3.85 \pm 0.34\%$ to $6.10 \pm 0.54\%$ (Table 3). PF90%:BGF10% recorded the highest moisture content ($6.10 \pm 0.54\%$) which was significantly different ($p > 0.05$) from the moisture content of the other flour samples. The moisture content of the other flour samples was in the range of $3.85 \pm 0.34\%$ to $4.36 \pm 0.21\%$ and was not significantly different

($p > 0.05$). The control flours (i.e. PF100% and BGF100%) had moisture contents of $4.19 \pm 0.29\%$ and $4.36 \pm 0.21\%$, respectively (Table 3). The mean moisture values of the flour samples were found to be low (below 10%), hence their storage stability will be enhanced and they will keep much longer.

Kiin-Kabari et al. (2015) reported a mean moisture content of 5.8% for both 100% PF and BGF. Also, Abdualrahman et al. (2012) reported a mean moisture content of 7.5% for BGF. Oyeyemi et al. (2019) reported the mean moisture content of plantain flour to be 8.70%. According to the AACC (1999) standard for flour, the moisture content is not supposed to exceed 14%. However, moisture content below 15.5% has also been reported for some other standards. Thus, the moisture content obtained in this study were much lower than the standard. According to Anajekwu et al. (2020), the moisture content of flour is relevant as it serves as the shelf life and stability indicator. Low levels of moisture inactivate the activity of enzymes thus, preventing the growth of bacteria and fungi. Factors affecting the moisture content of flour include drying method and temperature, method of unit operation, and experimental procedure (Muneer, 2015).

3.1.2. Protein

The protein content of the flour samples ranged from $2.13 \pm 0.04\%$ to $20.35 \pm 0.03\%$ (Table 3). The percent proteins of PF85: BGF15% and PF80%:BGF20% were not significantly different ($p > 0.05$). All the other flour samples had protein contents that were significantly different ($p > 0.05$). PF100% had the least protein content ($2.13 \pm 0.04\%$) and BGF100% had the highest protein content ($20.35 \pm 0.03\%$) (Table 3). Generally, it was observed that as the content of BGF increased in the blends, the protein content also increased. Abdualrahman et al. (2012) reported the protein content of BGF100% to be 32.16%. Tan et al. (2020), also reported that the protein content present in Bambara groundnut flour ranges from 9.6% to 40% with an average of 23.6%. Thus, the percent

Table 3. Proximate composition of flour blends.

Flour blends (%)	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Carbohydrate (%)
PF100	4.36 ± 0.21^b	2.13 ± 0.04^e	0.13 ± 0.01^d	1.33 ± 0.20^b	92.12 ± 0.72^a
BGF100	4.19 ± 0.29^b	20.35 ± 0.03^a	3.51 ± 0.39^a	2.31 ± 0.27^a	69.50 ± 0.28^e
PF90:BGF10	6.10 ± 0.54^a	3.91 ± 0.01^d	0.43 ± 0.02^d	1.51 ± 0.04^{ab}	87.75 ± 0.08^b
PF85:BGF15	4.04 ± 0.43^b	5.47 ± 0.01^c	1.43 ± 0.02^c	1.76 ± 0.34^{ab}	87.54 ± 0.57^b
PF80:BGF20	4.11 ± 0.33^b	5.82 ± 0.01^c	2.64 ± 0.11^b	2.04 ± 0.17^{ab}	85.30 ± 0.44^c
PF75:BGF25	3.85 ± 0.34^b	9.07 ± 0.07^b	4.02 ± 0.02^a	1.30 ± 0.14^b	81.78 ± 0.78^d

Means \pm Standard deviations bearing the same letters in column are not significantly different from each other (Tukey's HSD Test, significance level $p > 0.05$). PF=Plantain Flour, BGF=Bambara Groundnut Flour.

protein content obtained in this study was within the range already reported. Also, Anajekwu et al. (2020) reported between 2.47% to 2.99% of protein in different plantain cultivars. Abioye et al. (2011) reported 4.54% protein content for plantain flour and Eleazu et al. (2011) reported 3.15% protein content for plantain flour. Thus, the protein content obtained in this study did not differ from those already reported. According to Tan et al. (2020), high protein content is desired in foods and glutamic acid is reported to be the most abundant amino acid in Bambara groundnut flour. It has been isolated and utilized as a flavor in foods. Other essential amino acids present in Bambara groundnut flour include leucine and lysine which are present in high concentrations (Tan et al., 2020). The high amount of essential amino acids present in Bambara groundnut flour makes it fitting for use in fortification and enriching other foods. Therefore, enriching plantain flour with Bambara groundnut flour, which is low in protein for the formulation of food products, as was done in this study, was appropriate.

3.1.3. Fat

Fat content ranged from $0.13 \pm 0.01\%$ to $4.02 \pm 0.04\%$ (Table 3). PF75%:BGF25% recorded the highest fat content of $4.02 \pm 0.04\%$ which was not significantly different ($p > 0.05$) from that of BGF100% ($3.51 \pm 0.39\%$). Fat content of PF100% ($0.13 \pm 0.01\%$) and PF90%:BGF10% ($0.43 \pm 0.02\%$) were not significantly different from each other. Sample PF80%: BGF20% had a fat content that was significantly different ($p > 0.05$) from the rest of the flour samples. The fat content of BFG100% was found to be high. Abioye et al. (2011) and Anajekwu et al. (2020) reported 0.75% fat content in plantain flour and 0.1% to 1.20% fat content in flours produced from different cultivars of plantain flour, respectively. These were not different from the $0.13 \pm 0.01\%$ fat content obtained for plantain flour in this study. Also, Tan et al. (2020) stated that the percentage of fat that has been reported ranges from 1.9% to 9.7 5%. Abdualrahman et al. (2012), reported 2.76% fat in a study of BGF. In this study, 3.15% was recorded and that agrees with the range reported by Tan et al. (2020) and is not significantly different from what was reported by Abdualrahman et al. (2012). According to Oyeyemi et al. (2019), the role of fat in baking includes addition of richness, flavor, and moisture to the baked goods. It also adds taste and provides a good mouthfeel to the product, creating tenderness by shortening gluten strands and aids in leavening.

3.1.4. Ash

Ash content ranged from $1.30 \pm 0.14\%$ to $2.3 \pm 0.27\%$ (Table 3). BGF100% recorded the highest ash content of $2.31 \pm 0.27\%$ which was significantly different ($p < 0.05$) from that of the other flours. PF90%:BGF10%, PF85%:BGF15% and PF80%:BGF20% had percent ash contents (i.e. $1.51 \pm 0.04\%$, $1.76 \pm 0.34\%$ and $2.04 \pm 0.17\%$ respectively) that were not significantly different ($p > 0.05$). PF75%:BGF25% and PF100% recorded ash contents ($1.30 \pm 0.14\%$ and $1.33 \pm 0.20\%$, respectively) that were not significantly different ($p > 0.05$). Ash content reported by Abioye et al. (2011) was 1.96% for plantain flour. Eleazu et al. (2011) reported 5.5%, Kiin-Kabari et al. (2015) reported 1.2% and Anajekwu et al. (2020) reported a range of 2.01% to 3.69% for the ash content of plantain flour. Also, Abdualrahman et al. (2012) reported 1.70% ash content for Bambara groundnut flour. Thus, the $1.33 \pm 0.20\%$ of ash content reported for plantain flour in this study was in agreement with Kiin-Kabari and Banigo (2015) who reported it as 1.2%. The ash content of Bambara groundnut flour ($2.31 \pm 0.17\%$) was comparable to that of Abdualrahman et al. (2012) (1.70%). The ash content of flour refers to the mineral content which is quantified by burning the flour to ash and measuring the remains (Greenway, 2018). Greenway (2018), mentioned that, ash content in flour is influenced by the bran and germ present in the grain or nut as well as temperature and time combination for drying. Thus, the differences in percent ash content of flours in this study may be attributed to these factors as well as the variety of the raw material (Bambara and plantain). Higher ash content contributes to the flavor of the product and the nutrients but also negatively affects the gluten strength (Greenway, 2018).

3.1.5. Carbohydrate

Percent carbohydrate ranged from $69.50 \pm 0.28\%$ to $92.12 \pm 0.72\%$ (Table 3). PF100% had the highest carbohydrate content of $92.12 \pm 0.72\%$ and BGF100% had the least carbohydrate content of $69.50 \pm 0.28\%$. It was observed that the carbohydrate content increased as plantain flour increased in the flour blends. Plantain flour has been reported to have a high amount of starch compared to Bambara groundnut flour. Abioye et al. (2011) reported 83.1% carbohydrate content and Anajekwu et al. (2020) reported a range of 85.27% to 86.95% for the carbohydrate content of plantain flour. Comparing these to the carbohydrate content recorded in this study ($92.12 \pm 0.72\%$), it was observed to be higher. This

may result from the method used in obtaining the carbohydrates (difference method) as well as varietal differences. While Tan et al. (2020) reported an approximate carbohydrate content of 64.4% for Bambara groundnut flour, Abdulrahman et al. (2012) reported 86.57%. The carbohydrate content of $69.50 \pm 0.28\%$ obtained for Bambara groundnut flour in this study falls within the range reported. Functionally, carbohydrates are relevant in the bakery industry. Simsek (2018) mentioned the following as some of the functional characteristics of carbohydrates in baking: they act as gelling agents; starch damages the maintenance of sufficient gas produced by yeast and destroys the formation of fermentable carbohydrates. Thus, carbohydrate is a crucial agent required in flour to obtain a high quality baked product.

3.2. Functional properties of flour blends

3.2.1. Water absorption capacity

According to Yusufu and Ejeh (2018), water absorption is the amount of water absorbed and retained by flour in order to obtain the consistency desired in a food product during processing. The addition of too much or less amount of water to flour will make the food product too sticky to undergo processing (Oyeyemi et al., 2019). From Table 4, water absorption of 100% plantain flour recorded was the highest, with 100% Bambara groundnut flour showing the least. The WAC ranged from $50.81 \pm 0.53\%$ to $66.43 \pm 0.02\%$ at 27°C and $51.20 \pm 0.52\%$ to $76.53 \pm 1.16\%$ at 70°C.

It can also be observed that WAC increased with the increase in plantain flour content in the blends. It was evident that WAC decreased with the increase in Bambara groundnut flour in the blends from PF75%:BGF25% to PF85%:BGF15%, respectively. Plantain flour had a higher WAC than Bambara groundnut flour (Table 4). Thus, it will be preferred in food product formulations for which high water retention is desirable. Also, (at temperatures of 27 and 70°C) the mean WAC for BGF100% was

Table 4. Water absorption capacity of flour blends at 27°C and 70°C.

Flour blends (%)	27°C	70°C
PF100	66.43 ± 0.02^a	76.53 ± 1.16^a
BGF100	50.81 ± 0.53^b	51.20 ± 0.52^a
PF90:BGF10	63.17 ± 0.89^b	76.07 ± 0.51^a
PF85:BGF15	63.13 ± 0.76^c	74.52 ± 0.84^b
PF80:BGF20	59.51 ± 0.09^c	69.69 ± 0.59^b
PF75:BGF25	60.39 ± 1.07^d	67.73 ± 0.58^c

Means \pm Standard deviations bearing the same letters in column are not significantly different from each other (Tukey's HSD Test, significance level $p > 0.05$). PF=Plantain Flour, BGF=Bambara Groundnut Flour.

significantly different ($p > 0.05$) from all the other flours. Generally, WAC increased with increase in temperature. Suresh et al. (2014) attributed the decrease in flour WAC of the flour's lower availability of polar amino acids. Ajala et al. (2018) also mentioned an increase in temperature during drying results in lower moisture content in flour, leading to an increase in water absorption. Also, the increase in WAC of flour was influenced by increases in amylose leaching and solubility and the loss of starch crystalline structure. Thus, flour that has a higher WAC may have quite a number of hydrophilic components, including polysaccharides (Suresh et al., 2014). Uzoukwu et al. (2015) classified flour as: WAC $> 63\%$ as very strong flour, 62–58% as strong flour, 54–60% as medium strength flour and $< 55\%$ as weak flour. Thus, all the flour blends, including the 100% plantain, can be described as strong and very strong flour, respectively, with only the BGF100% being classified as weak flour. However, different bakery products require different WAC in order to obtain a quality product (Ajala et al., 2018). WAC is an important factor during the production of food products such as dough, processed cheese and bakery products (Suresh et al., 2014). WAC influences the following qualities of food products; loaf volume, yield, proofing, final product attributes and shelf life of the product (Yasumatsu et al., 1972).

3.2.2. Bulk density

The bulk density of flour formulations ranged from 0.81 g/ml to 0.98 g/ml (Table 5). The mean bulk densities of PF100% and PF90%:BGF10% were not significantly different ($p > 0.05$). Bulk density of PF80%:BGF20% and PF75%:BGF25% was not significantly different ($p > 0.05$) with BGF100% having the least bulk density (Table 5). The bulk density increased with an increase in plantain flour per, the results obtained. It can be said that plantain flour had a higher bulk density ($0.98 \pm 0.03\%$) than Bambara groundnut flour (0.81 ± 0.02). Also, the increase in Bambara groundnut flour for the various blends led to a decrease in bulk density. Anajekwu et al. (2020) reported similar observations in a study of flour formulations. Kiin-Kabari et al. (2015) also reported a high bulk density for plantain flour compared to Bambara groundnut and wheat flour. It was realized that, as the bulk density increased, the flour became denser. Such information is relevant in selecting a suitable packaging material for a product (Kiin-Kabari et al., 2015). The bulk density of flour is associated with the particle size and initial moisture content of

Table 5. Functional properties of flours.

Flour blends (%)	Bulk density (g/ml)	Oil absorption capacity (%)	Foaming capacity (%)	Foaming stability (%)	Emulsion activity (%)	Emulsion stability (%)
PF100	0.98 ± 0.03 ^a	51.04 ± 1.07 ^a	3.72 ± 0.09 ^c	1.90 ± 0.00 ^a	40.00 ± 0.00 ^b	44.64 ± 0.91 ^c
BGF100	0.81 ± 0.02 ^c	53.47 ± 0.97 ^a	5.47 ± 0.03 ^b	1.90 ± 0.00 ^a	49.76 ± 1.67 ^a	62.73 ± 1.03 ^a
PF90:BGF	0.98 ± 0.05 ^a	50.40 ± 0.66 ^a	3.79 ± 0.04 ^c	1.90 ± 0.00 ^a	42.87 ± 0.39 ^b	47.50 ± 0.71 ^{bc}
PF85:BGF15	0.89 ± 0.02 ^b	49.99 ± 3.75 ^a	3.75 ± 0.04 ^c	1.90 ± 0.00 ^a	42.70 ± 0.99 ^b	49.52 ± 0.82 ^b
PF80:BGF20	0.92 ± 0.02 ^{ab}	44.68 ± 1.39 ^b	5.52 ± 0.06 ^b	1.90 ± 0.00 ^a	42.53 ± 0.10 ^b	48.36 ± 0.62 ^b
PF75:BGF25	0.97 ± 0.03 ^{ab}	53.80 ± 3.68 ^a	6.18 ± 0.05 ^a	1.60 ± 0.00 ^a	40.37 ± 0.52 ^b	44.73 ± 1.03 ^c

Means ± Standard deviations sharing the same letter in column are not significantly different from each other (Tukey's HSD Test, significance level $p > 0.05$). PF=Plantain Flour, BGF=Bambara Groundnut Flour.

flour (Suresh et al., 2014). Suresh et al. (2014) also stated that flours with high bulk density were appropriate for food preparation and helped in reducing paste thickness. Those with low bulk densities were suitable for the formulation of complementary foods.

3.2.3. Oil absorption capacity (OAC)

Oil absorption capacity (OAC) is the ability of flour to absorb and retain oil. From Table 5, the percent OAC of the controls (i.e. 100% plantain and Bambara groundnut flour) and their blends ranged from 44.68 ± 1.39% to 53.8 ± 3.680%. There was no significant difference ($p > 0.05$) between the percent OAC of flour blends with the exception of PF80%:BGF20% who's OAC was different ($p > 0.05$) from the other flour samples. However, BGF100% recorded a higher OAC (53.47 ± 0.97) than PF100% (51.04 ± 1.07). Thus, it was observed that an increase in the proportion of BGF100% in the blends led to an increase in OAC. According to Yusufu and Ejeh (2018), protein concentration and their conformational characteristics influence fat absorption. Also, studies have reported that differences in variations in the content of non-polar side chains, which might bind to the hydrocarbon side chains of oils, explain the reason why there are differences in the OAC. Bambara groundnut flour contains much more protein (20.35 ± 0.03) than plantain flour (2.13 ± 0.04%). According to Suresh et al. (2014) and Yusufu and Ejeh (2018), high OAC is important for flavor retention, mouthfeel, food and extending the shelf life of bakery products.

3.2.4. Foaming capacity (FC) and stability (FS)

Suresh et al. (2014) and Awuchi et al. (2019) defined foaming capacity as the amount of interfacial area generated by whipping food or flour, and foaming stability as a measure of the time required to lose either 50% of the liquid or 50% of the volume from the foam. Foam is a colloidal system consisting of numerous gas bubbles that are entrapped in a liquid or solid. From Table 5, FC ranged from 3.72 ± 0.09% to 6.18 ± 0.05% and FS from 1.60 ± 0.00% to 1.90 ± 0.00% for all the flours, respectively. PF75%:BGF25% recorded

the highest FC (6.18 ± 0.05%), followed by PF80%: BGF20% (5.52 ± 0.06%) and BGF100% (5.47 ± 0.03%). BGF100% recorded a higher FC (5.47 ± 0.03%) than PF100% (3.72 ± 0.09%). Therefore, it was observed that FC increased with an increase in the proportion of BGF for the various flour blends. According to Awuchi et al. (2019), protein is mainly responsible for the foaming. The higher level of protein in BGF compared to PF is thus the reason why BGF100% recorded a higher FC than PF100% and this also influenced the FC of the flour blends. According to Awuchi et al. (2019), flours with higher FC normally showed lower FS due to the fact that flours with higher FC may develop large air bubbles encircled by thinner, less flexible protein films. These air bubbles may easily collapse, leading to lower FS. However, that trend was not observed in this study as well as those of Suresh et al. (2014) and Mune and Sogi (2016). Foaming capacity and stability are crucial in flour quality assessment and food product formulation. According to Green et al. (2013), foaming capacity and most importantly, are its stability are relevant sensory attributes of food products that appeal to consumers. It is an important functionality in food product formulation.

3.2.5. Emulsion activity (EA) and stability (ES)

Emulsion activity (EA) ranged from 40.00 ± 0.00 to 49.76 ± 1.67%. All the other flours, with the exception of BGF100% had an EA that were not significantly different ($p > 0.05$). For the controls, BGF100% had EA of 49.76 ± 1.69 (the highest) while PF had EA of 40.00 ± 0.00% (the least). Emulsion stability (ES) increased among the flour blends as BGF increased. Emulsion activity and stability are affected by many factors, including solubility, pH and the concentration of the flour (Adebowale et al., 2005). Emulsion is formed and stabilized by the surface active agents creating electrostatic repulsion on the oil droplet surface (Suresh et al., 2014). This characteristic of protein is crucial for application in food products such as cake, coffee whiteners and frozen desserts (Adebowale et al., 2005). During processing, EA and ES give the food product strength to withstand the

mechanical pressure that the food may be subjected to.

3.3. Characteristics of flour

3.3.1. pH

pH of flour ranged from 5.92 to 6.62 (Table 6). BGF100% had the highest pH (6.62 ± 0.00) and PF100% had the least pH (5.80 ± 0.00). The pH of composite flours increased as %BGF% increase. There was no significant difference ($p > 0.05$) between the pH recorded for PF75%:BGF25% (6.11 ± 0.00), PF90%:BGF10% (5.96 ± 0.01) and PF85%:BGF15% (5.99 ± 0.02). PF80%:BGF20% had a pH that was significantly different ($p < 0.05$) from that of the other flour blends.

Eltayeb et al. (2011) reported a pH of 6.0 for Bambara groundnut flour and Abioye et al. (2011) reported a pH of 5.50 for plantain flour. Their findings were in line with the range of values recorded in this study. In baking, pH plays a vital role by controlling yeast activity, amylolytic action, properties of gluten and regulation of the activity of certain microbes (Pyler & Gorton, 2019). It also used to assess fruit maturity and post-harvest quality characteristics serves as a measure of fruit maturity and post-harvest quality characteristics (Ishmael, 2011). The pH of flour is also affected by processing temperature and material pre-treatment (Ishmael, 2011).

3.3.2. Color

From Table 6, the lightness (L) of flour ranged from 68.50 ± 0.00 to 74.77 ± 0.60 , redness (a^*) ranged from -0.48 ± 0.61 to 0.37 ± 0.05 , yellowness (b^*) ranged from 14.97 ± 0.15 to 18.00 ± 0.44 and overall color change (ΔE) ranged from 16.55 ± 0.23 to 21.18 ± 0.19 . There was a significant difference ($p > 0.05$) between the lightness (L) of PF100% (74.77 ± 0.60) and that of BGF100% (68.50 ± 0.00). Lightness (L) increased as a proportion of the BGF100% increase in the flour blends. Redness (a^*) also increased as BGF100% increase in the flour Blends. There was no significant difference ($p > 0.05$) between the yellowness (b^*) of PF100% (14.97 ± 0.15) and BGF100% (15.10 ± 0.20).

There was no significant differences ($p > 0.05$) observed in the yellowness (b^*) of the PF90%:BGF10% (16.80 ± 0.36), PF85%:BGF15% (16.97 ± 0.21), and PF75%:BGF25% (17.07 ± 0.33) with the exception of BGF80%:PF20% whose yellowness (b^*) was significantly different ($p > 0.05$) from the other blends. It was observed that, yellowness (b^*) increased as BGF100% increase in the flour blends. The overall color change (ΔE) increased as the percentage of BGF100% in the flour blends increased. It was observed that for the flour blends, as BGF100% increased, lightness (L), yellowness (b^*), redness (a^*) and overall color change (ΔE) of the flours increased. Factors that contribute to the differences in color include plantain and Bambara groundnut varieties, milling practices, and use of bleaches during processing (Ken, 2016). Anajekwu et al. (2020) also mentioned that browning which results from enzyme activity, affects flour color as well as the drying method. The determination of the color of flour is crucial because it allows for quality assessment of the flour during processing to ensure product conformance to standards and ensuring minimization of economic losses as a result of non-conformance (Ken, 2016).

3.4. Quality characteristics of doughnuts

3.4.1. pH, net-weight, thickness, texture (hardness) and diameter of doughnuts

From the results presented in Table 7, pH of doughnuts ranged from 7.07 ± 0.01 to 7.22 ± 0.02 . There was a significant difference ($p > 0.05$) between doughnuts produced from PF100% (7.20 ± 0.01) and BGF100% (7.07 ± 0.01). There was no significant difference ($p > 0.05$) between the pH of doughnuts produced from the flour blends. pH of flour before doughnut production ranged from 5.80 ± 0.00 to 6.62 ± 0.00 (Table 6). After doughnut production, however, the pH of doughnuts increased to a range of 7.07 ± 0.01 to 7.22 ± 0.02 . This change in pH was probably due to the added ingredients to the dough. The pH of baked food is very crucial as it influences the shelf

Table 6. pH and color of flour blends.

Flour blends (%)	pH	Lightness (L^*)	Redness (a^*)	Yellowness (b^*)	ΔE
PF100	5.80 ± 0.00^e	68.50 ± 0.00^d	0.00 ± 0.02^{bc}	14.97 ± 0.15^c	16.55 ± 0.23^c
BGF100	6.62 ± 0.00^a	74.77 ± 0.60^a	2.35 ± 0.08^a	15.10 ± 0.20^c	21.18 ± 0.19^a
PF90:BGF10	5.96 ± 0.01^c	70.16 ± 0.65^c	-0.48 ± 0.61^c	16.80 ± 0.36^b	18.99 ± 0.68^b
PF85:BGF15	5.99 ± 0.02^c	70.09 ± 0.27^c	0.02 ± 0.05^{bc}	16.97 ± 0.21^b	19.04 ± 0.33^b
PF80:BGF20	5.92 ± 0.01^d	71.28 ± 0.85^{bc}	0.09 ± 0.05^{bc}	18.00 ± 0.44^a	20.60 ± 0.92^a
PF75:BGF25	6.11 ± 0.00^c	72.30 ± 0.56^b	0.37 ± 0.05^b	17.07 ± 0.33^b	20.65 ± 0.65^a

Means \pm Standard deviations bearing the same letters in column are not significantly different from each other (Tukey's HSD Test, significance level $p > 0.05$). PF=Plantain Flour, BGF=Bambara Groundnut Flour.

Table 7. Weight, diameter, thickness, hardness and pH of doughnuts.

Flour blends (%)	Weight (g)	Diameter (inches)	Thickness (inches)	pH	Hardness [Gram-Force] (gf)
PF100	17.58 ± 1.03 ^a	1.94 ± 0.09 ^a	0.62 ± 0.04 ^b	7.20 ± 0.01 ^a	20,575.69 ± 5,510.80 ^b
BGF100	14.64 ± 0.45 ^b	1.88 ± 0.04 ^{ab}	0.64 ± 0.05 ^{ab}	7.07 ± 0.01 ^c	30,265.66 ± 6,650.15 ^a
PF90:BGF10	15.54 ± 0.66 ^b	1.80 ± 0.00 ^b	0.64 ± 0.05 ^{ab}	7.21 ± 0.01 ^a	21,267.59 ± 3,898.23 ^b
PF85:BGF15	15.83 ± 0.42 ^b	1.80 ± 0.07 ^b	0.70 ± 0.00 ^a	7.14 ± 0.01 ^b	19,081.94 ± 3,998.28 ^b
PF80:BGF20	14.87 ± 0.74 ^b	1.90 ± 0.07 ^{ab}	0.60 ± 0.00 ^b	7.22 ± 0.02 ^a	21,183.60 ± 1,641.39 ^b
PF75:BGF25	15.28 ± 0.37 ^b	1.96 ± 0.05 ^a	0.60 ± 0.00 ^b	7.20 ± 0.00 ^a	20,008.63 ± 4,774.98 ^b

Means ± Standard deviations bearing the same letters in column are not significantly different from each other (Tukey's HSD Test, significance level $p > 0.05$). PF = Plantain Flour, BGF = Bambara Groundnut Flour.

life of the product. However, the pH of the doughnuts recorded will possibly create room for molds and yeast, as well as other microorganisms, to operate which could lead to spoilage of the food product if not stored under suitable conditions of temperature and relative humidity (Cauvain & Young, 2009).

The weight of doughnuts ranged from 14.64 ± 0.45g to 17.58 ± 1.03g (Table 7). There was a significant difference ($p > 0.05$) between weight of doughnuts produced from PF100% (17.58 ± 1.03g) and that of BGF100% (14.64 ± 0.45g). There was no significant difference ($p > 0.05$) between the weights of doughnuts produced from all the flour blends. PF100% yielded doughnuts with the highest weight and also influenced the weight of the formulations due to its bulkiness. The weight of a food product is relevant for packaging and labeling purposes and quality assurance, and conformance to standards (Crown et al., 2016).

The diameter of doughnuts ranged from 1.80 ± 0.00 to 1.96 ± 0.05 inches (Table 7). There was a significant difference ($p > 0.05$) between the diameters of doughnuts produced from PF100% (1.94 ± 0.09 inches) and those produced from BGF100%. Both PF90%:BGF10% and PF85%:BGF15% flour blend doughnuts had the same diameters (1.80 ± 0.00 and 1.80 ± 0.07 inches, respectively). Doughnuts produced from PF80%:BGF20% and PF75%:BGF20% had diameters of 1.90 ± 0.07 and 1.96 ± 0.05 inches (Table 7). Differences in the diameters of doughnuts may be as a result of variations in the scoops of dough placed into the ring-like holes of the doughnut baker.

The thickness of doughnuts also ranged from 0.60 ± 0.00 to 0.70 ± 0.00 inches (Table 7). The highest thickness (0.70 ± 0.00 inches) was recorded by PF85%:BGF15% and the lowest were recorded by PF80%:BGF20% and PF75%:BGF25% (0.60 ± 0.00 inches). Doughnuts produced from B100% and PF90%:BGF10% had the same thickness (0.64 ± 0.05 inches) and doughnuts produced from PF100% recorded a thickness that was significantly different ($p > 0.05$) from all the other doughnuts.

The force needed to compress the doughnuts ranged from 19,081.94 ± 3,998.28 to 30,265.66 ± 6,650.15 gram force (Table 7). The force required to compress

doughnuts made from BGF100% (30,265.66 ± 6,650.15 gram force) differed significantly different ($p > 0.05$) from that required to compress doughnuts made from other flour blends. Thus, doughnuts produced with BGF100% were harder than those produced with the other flour blends. The force used to compress the doughnuts was quite high, indicating that the products were quite hard. This was confirmed by the comments from panelists, who indicated that the products were quite harder than the regular doughnut. This may be because the freshness of the product has decreased and the products have hardened with time. The type of flour used is also a contributing factor, as plantain flour showed a hardening property. Kiin-Kabari and Banigo (2015) reported that, addition of plantains to other flours reduced the gluten content of the flours, affecting its texture. Thus, early utilization of product, addition of the texturants including emulsifiers, enzymes and hydrocolloids and certain carbohydrates, can help regulate the texture of the doughnuts while improving consumer liking (Donna, 2013).

3.4.2. Color of doughnuts

From Table 8, lightness (L) of doughnuts ranged from 38.20 ± 0.59 to 55.20 ± 0.90, redness (a^*) ranged from 5.53 ± 0.38 to 12.81 ± 1.20, yellowness (b^*) ranged from 23.48 ± 0.36 to 39.90 ± 1.60 and overall color change (ΔE) of doughnuts ranged from 55.34 ± 1.72 to 61.19 ± 0.76. There was a significant difference ($p < 0.05$) between the lightness (L) of doughnuts produced from PF100% (43.55 ± 0.83) and BGF100% (55.20 ± 0.90). There was no significant difference ($p > 0.05$) between the lightness (L) of doughnuts produced from PF90%:BGF10% (39.25 ± 0.76), PF80%:BGF20% (38.20 ± 0.59) and PF75%:BGF25% flour blends. The lightness (L) of doughnuts increased as the proportion of BGF100% in flour blends increased. There was a significant difference ($p > 0.05$) between the redness of doughnuts produced from PF100% (9.84 ± 0.87) and BGF100% (12.81 ± 1.20). Significant differences ($p > 0.05$) were also observed in the redness (a^*) of the doughnuts produced from the flour blends.

Table 8. Color of doughnuts.

Flour blends (%)	Lightness (L*)	Redness (a*)	Yellowness (b*)	ΔE
PF100	43.55 ± 0.83 ^b	9.84 ± 0.87 ^b	28.10 ± 0.84 ^b	58.06 ± 1.04 ^{bc}
BGF100	55.20 ± 0.90 ^a	12.81 ± 1.20 ^a	39.90 ± 1.60 ^a	56.41 ± 0.37 ^{cd}
PF90:BGF10	39.25 ± 0.76 ^c	11.07 ± 0.28 ^{ab}	23.48 ± 0.36 ^c	60.19 ± 0.54 ^{ab}
PF85:BGF15	44.22 ± 0.99 ^b	5.53 ± 0.38 ^c	26.96 ± 1.56 ^b	55.34 ± 1.72 ^d
PF80:BGF20	38.20 ± 0.59 ^c	10.03 ± 1.02 ^b	23.97 ± 0.23 ^c	61.19 ± 0.76 ^a
PF75:BGF25	40.42 ± 1.67 ^c	10.67 ± 0.20 ^b	23.99 ± 0.81 ^c	59.49 ± 0.80 ^{ab}

Means ± Standard deviations bearing the same letters in column are not significantly different from each other (Tukey's HSD Test, significance level $p > 0.05$). PF=Plantain Flour, BGF=Bambara Groundnut Flour.

However, no significant difference ($p > 0.05$) was observed in the redness (a^*) doughnuts produced from PF80%:BGF20% (10.0 ± 1.02) and PF75%:BGF25% (10.67 ± 0.20). Redness (a^*) was observed to have increased with the increase in PF100% flour in the doughnuts produced from the flour blends. There was a significant difference ($p > 0.05$) between the yellowness (b^*) of doughnuts produced from PF100% (28.10 ± 0.84) and BGF100% (39.90 ± 1.60). There were no significant differences ($p > 0.05$) observed in the yellowness of doughnuts produced from PF90%:BGF10% (23.48 ± 0.36), PF80%: BGF20% (23.97 ± 0.23) and PF75%:BGF25% (23.99 ± 0.81) with the exception of doughnuts produced from BGF85%:PF15% (26.96 ± 1.56) whose yellowness (b^*) was significantly different ($p > 0.05$) from the other formulations. With the exception of BGF85%:PF15%, the yellowness (b^*) of doughnuts increased with an increase in BGF100% in the flour blends. There was a significant difference ($p > 0.05$) in the overall color change (ΔE) of doughnuts produced from PF100% (58.06 ± 1.04) and BGF100% (56.41 ± 0.37). The overall color change (ΔE) of BGF90%:PF10% (60.19 ± 0.54) and BGF75%:PF25% (59.49 ± 0.80) doughnuts produced from flour blends were not significantly different ($p > 0.05$), but those of PF80%:BGF20% (61.19 ± 0.76) and BGF85%:PF15% (55.34 ± 1.72) were ($p < 0.05$). The factors which contributed to the differences in color of the baked products include plantain and Bambara groundnut variety and processing procedure (Ken, 2016). Determination of the color of baked products such as doughnuts is crucial for quality assessment of the product (Ken, 2016). Also, as reported, color influences the acceptance of products by consumers hence determining the color of food products helps meet consumer needs and ensures profitability.

3.4.3. Microbial quality of doughnuts

A microbial analysis of doughnuts was carried out to ensure that they were free from contamination and safe for consumption. No growth of coliforms was

Table 9. Microbial analysis of doughnuts.

Doughnut	Total coliform count (CFU/g)	Total plate count (CFU/g)	Yeast and mold (CFU/g)
PF100	NG	NG	NG
BGF100	NG	4.5 ± 0.71	NG
PF90:BGF10	NG	20.5 ± 0.71	NG
PF85:BGF15	NG	NG	NG
PF80:BGF20	NG	NG	NG
PF75:BGF25	NG	8.5 ± 0.71	NG

PF=Plantain Flour, BGF=Bambara Groundnut Flour, NG=No Growth.

observed in any of the doughnuts. Also, no growth was observed for yeast and molds. The total plate count was 4.5 ± 0.71 CFU/g for doughnuts made from BGF100%, 20.5 ± 0.71 CFU/g for doughnuts made from PF90%:BGF10%, and 8.5 ± 0.71 CFU/g for doughnuts made from PF75%:BGF25% (Table 9). There was no growth observed for the total plate count for doughnuts produced from PF100%, PF85%:BGF15% and PF80%:BGF20% (Table 9). The ideal total plate count for analysis of foods and cosmetics is 25–250 CFU/g (Gilchrist et al., 1977). Thus, the microbial counts reported for the total plate count for the doughnuts fell within or below the critical limit. Therefore, all the doughnuts were safe for consumption.

3.4.4. Sensory evaluation of doughnuts

According to Lawless and Heymann (2010), sensory evaluation has to do with the accurate and precise measurement of human responses to certain characteristics of food while being objective and lowering the level of biases that result from the brand of food being tested as well as other information that influences consumer perception of a particular food product. Sensory analysis was carried out to assess consumer acceptance of doughnuts produced from plantain and Bambara groundnut and their blends. Consumers assessed characteristics such as appearance, color, aroma, texture, taste, mouthfeel and overall liking.

From the results in Table 10, there was no significant difference ($p > 0.05$) in the appearance score of doughnuts produced from all the flours. Scores for appearance ranged from 6.73 ± 1.76 to 7.10 ± 2.04 . The appearance scores for all doughnuts were approximately 7, indicating that the doughnuts were moderately similar. As a result, the appearance of all doughnut samples tested was moderately liked (7).

Color scores ranged from 6.69 ± 1.64 to 7.10 ± 1.99 (Table 10). There was also no significant difference ($p > 0.05$) between the color liking scores for all the doughnut samples. The approximate color score for all the doughnuts was 7; meaning the colors of all the doughnut samples were moderately liked by the consumers.

Table 10. Sensory evaluation of doughnut.

Flour blends (%)	Appearance liking	Color liking	Aroma liking	Texture liking	Taste liking	Mouthfeel liking	Overall liking
PF100	6.74 ± 1.71 ^a	6.75 ± 1.63 ^a	7.40 ± 1.29 ^a	6.15 ± 1.80 ^a	6.75 ± 1.76 ^a	5.80 ± 2.14 ^{ab}	6.65 ± 1.60 ^a
BGF100	7.10 ± 2.04 ^a	7.10 ± 1.99 ^a	6.24 ± 2.28 ^b	6.24 ± 1.97 ^a	5.24 ± 2.39 ^b	5.55 ± 2.14 ^b	5.79 ± 2.16 ^b
PF90:BGF10	6.73 ± 1.69 ^a	6.71 ± 1.72 ^a	7.19 ± 1.47 ^a	6.71 ± 1.57 ^a	7.10 ± 1.47 ^a	6.56 ± 1.71 ^a	7.10 ± 1.35 ^a
PF85:BGF15	6.84 ± 1.64 ^a	6.93 ± 1.57 ^a	7.26 ± 1.33 ^a	6.33 ± 1.54 ^a	6.55 ± 1.75 ^a	6.09 ± 2.02 ^{ab}	6.78 ± 1.50 ^a
PF80:BGF20	6.80 ± 1.53 ^a	6.69 ± 1.64 ^a	7.38 ± 1.30 ^a	6.68 ± 1.61 ^a	7.00 ± 1.50 ^a	6.44 ± 1.74 ^a	7.00 ± 1.35 ^a
PF75:BGF25	6.73 ± 1.76 ^a	6.74 ± 1.74 ^a	7.26 ± 1.13 ^a	6.63 ± 1.72 ^a	7.01 ± 1.45 ^a	6.39 ± 1.91 ^{ab}	7.00 ± 1.48 ^a

Means ± standard deviations sharing the same letters in column are not significantly different from each other (Tukey's HSD Test, significance level $p > 0.05$). PF = Plantain Flour, BGF = Bambara Groundnut Flour.

Aroma scores ranged from 6.24 ± 2.28 to 7.40 ± 1.29 (Table 10). Apart from doughnuts produced from BGF100% which had an aroma liking score of 6.24 ± 2.28 , no significant difference ($p > 0.05$) was observed for the aroma liking score of doughnuts produced from the other flour blends. Thus, while doughnuts produced from BGF100% were liked slightly, those produced from the other flours were liked moderately. The scores for texture ranged from 6.15 ± 1.80 to 6.68 ± 1.61 . No significant differences ($p > 0.05$) were observed between the texture likings of all the samples. However, doughnuts produced from PF75%:BGF25%, PF80%:BGF20, and PF90%:BGF10% flour blends had an approximate texture liking score of 7 indicating that those doughnuts were liked moderately while those produced from PF85%: BGF15%, PF100% and BGF100% had a score of 6, indicating those were liked slightly.

Taste scores ranged from 5.24 ± 2.39 to 7.10 ± 1.47 (Table 10). Doughnuts produced from BGF100% had a taste score of approximately 5, indicating that the taste of that sample was neither liked nor disliked. The approximate score for the other doughnut samples was 7, indicating that their taste was moderately liked and that no significant differences ($p > 0.05$) were observed between their mean tastes.

The mouthfeel score ranged from 5.55 ± 2.14 to 6.56 ± 1.71 (Table 10). Doughnuts made with PF90%:BGF10% had an approximate mouthfeel score of 7, indicating moderate likeness, whereas those made with the other blends were liked slightly. Overall, all doughnut samples were liked moderately (7 overall likeness score), with no significant difference ($p > 0.05$) between their scores, with the exception of doughnuts produced from BGF100% which were liked slightly (6 overall likeness score). Doughnuts produced from a PF90%:BGF10% flour blend was liked moderately (7.10) (Table 10) in terms of aroma, texture, taste, mouthfeel and overall liking. However, similar likeness score (approximately 7) was reported for the doughnuts produced from the other flour blends.

Therefore, based on consumer preference, doughnuts produced from PF90%: BGF10% will be suitable

for production on a larger scale for economic purposes. However, with the exception of mouthfeel, no significant differences ($p > 0.05$) were observed between the sensorial characteristics and the overall liking of doughnuts produced from the various flour blends (Table 10). Thus, from the results of the sensory evaluation, selecting PF75%: BGF25% flour blend for product formulation, such as doughnuts, will ensure that enough Bambara groundnut is present in the doughnuts to increase the amount of protein, leading to an increase in the nutrient intake of consumers.

4. Conclusion

Results from this study indicated that plantain flour (PF100%) showed higher swelling capacity, water absorption capacity and bulk density. The same was true for Bambara groundnut flour (BGF100%) with regard to its functional properties. It was realized that as the amount of plantain flour increased in the flour blends, values for the various functional properties (oil absorption capacity, foaming capacity and stability, emulsion activity and stability) also increased. No significant differences were observed in the moisture content of the flour blends. Protein, fat and ash contents were higher in the Bambara groundnut flour (BGF100%), and carbohydrate was high in the plantain flour (PF100%). The pH of the flours were slightly acidic. Microbial analysis of the doughnuts showed that they were safe for consumption. Sensory analysis revealed that doughnuts made from BGF100% flour had the most appealing color. Overall, consumers preferred doughnuts made with 90% plantain and 10% Bambara groundnut (PF90%:BGF10%) flour blend. However, no significant differences ($p > 0.05$) were observed in the overall liking of the doughnuts made from the various flour blends. The utilization of these food commodities (plantain and Bambara groundnuts) by incorporating them in various food products such as doughnuts will provide an alternative choice for consumers and also, processors can reduce their cost of production by using these flour blends for product formulations.

This will ultimately expand the utilization of these crops and improve food security.

Disclosure statement

The authors declare that there is no conflict of interest regarding the publication of this article.

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Data availability statement

The authors declare that the data supporting the findings of the study entitled 'Physico-chemical and Functional Properties of Unripe Plantain and Bambara Groundnut Flour Blends for Doughnut Production' are available within this article.

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