

Optimization of Legume-based stiff dough: Impacts on Composition and Functional Properties

Abstract

This study investigated the effect of optimization of process techniques for the production of Bambara groundnut flour and optimization of ingredient formulation for legume-based stiff dough, with an aim to improve nutritional composition and functional properties, while retaining its traditional appeal. The legume-based stiff dough comprised of fermented Bambara groundnut flour and three existing stiff dough staples (eba, pounded yam and fufu). The Bambara groundnut, yam and cassava tubers were processed into flour and mixed into different proportions of ratio 90:10, 80:20, 70:30, 60:40 and 100 was used as control. Sensory properties were evaluated to determine most acceptable blend. Most acceptable blend (70% fermented Bambara groundnut flour inclusion) was evaluated for proximate composition (moisture, protein, crude fat, crude fiber, ash and carbohydrate); and functional properties. All data obtained were subjected to appropriate statistical analysis. Protein content ranged from 1.31% to 4.24% and 14.63% to 16.26%; fat content ranged from 0.26% to 3.02% and 3.31% to 3.77%; fiber content ranged from 0.17% to 2.90% and 1.64% to 3.12%; ash content ranged from 0.37% to 1.38% and 2.63% to 2.84%; for stiff dough with 0% and 70% fermented Bambara groundnut flour inclusion respectively. The bulk density, water absorption capacity, least gelation concentration ranged between 1.54g/cm³ and 2.00g/cm³; 12% and 20%, 8% and 22% respectively and varied significantly different ($p < 0.05$) among samples. Sensory evaluation indicated significant difference ($p < 0.05$) among the samples, with 70% legume inclusion being most preferred in terms of texture. The findings of this study have shown that blending 70% of fermented (48hours) Bambara groundnut flour into 30% stiff dough (e.g., Eba) improved nutrient content up to 50% and enhanced functionality, offering valuable

insights for food manufacturers and consumers seeking healthier and more sustainable food options.

Keywords: Stiff dough, Bambara groundnut, Proximate composition, Sensory evaluation, Functional properties.

1.0 Introduction

Food optimization refers to the process of improving various aspects of food products to enhance their nutritional value, quality, taste, shelf life, production efficiency, and consumer acceptance. This process often involves adjusting ingredient ratios, processing methods, or formulations to achieve desired characteristics. Optimization of legume-based stiff dough offers a promising strategy to improve the health outcomes associated with staple foods in diverse populations. By addressing the need for functional foods that combine traditional dietary patterns with improved nutritional profiles, this research aligns with global health objectives, through dietary interventions (WHO, 2020).

Stiff dough is made by cooking and pounding starches like yam, cassava, plantain, or maize until they form a smooth, thick, and stretchy dough-like consistency e.g., eba, fufu, pounded yam etc. they are often called swallows. Eba is gelatinized garri. Garri is made from processed cassava tubers. To prepare Eba, hot boiled water is added to Garri, mixed and kneaded to form stiff dough. Traditionally, pounded yam is prepared by pounding boiled soft yams until stiff dough is formed. Alternatively, yam tubers can be processed into instant yam flour, stirred into boiling water until stiff dough is formed. Fufu is made from fermented wet paste of cassava. The fermented paste is cooked by boiling; it is then pounded to obtain stiff dough. Alternatively, the wet paste is pressed into a cake and dried to obtain fufu flour; the flour can be stirred into boiled water to obtain stiff

dough. They are usually consumed with soups and ingested by swallowing. Stiff dough food is widely consumed for their energy-dense properties; however, they are often limited in protein and micronutrient density. Enhancing the nutritional quality presents an important opportunity to improve public health outcomes, especially in communities where malnutrition is prevalent (Brand-Miller *et al.*, 2003). One approach to improving nutrition content for stiff dough staples is through ingredient modification particularly by adding legumes (Messina, 2014). Legumes are nutritionally rich, offering high levels of protein, dietary fiber, and bioactive compounds (Messina, 2014). Inclusion of legumes addresses protein-energy malnutrition (which is prevalent in many low- and middle-income countries); improves metabolic markers and contribute to better health outcomes (Michaelsen *et al.*, 2009; Gibson *et al.*, 2011).

Bambara Groundnut (*Vigna subterranea* L.) is one of the indigenous underutilized legumes which originated from West Africa. It is a sustainable, low-cost source of plant-based protein, unsaturated fatty acids and essential minerals. Bambara groundnut has the potential to play a role in combating food insecurity and malnutrition. It is extremely drought resistant and can be grown under extreme climatic conditions; hence it is a promising crop against global climatic changes (Agbenorhevi *et al.*, 2007). Traditionally Bambara groundnuts are processed by boiling, roasting, crushing into flour to prepare some local dishes like “okpa”, “akara”, “kunu” (Linnemann, 1988).

Modifications in diet can exert both positive and negative effects, making the shift toward nutrient-rich foods with functional health benefits more essential (Aschemann-Witzel *et al.*, 2020). This trend is largely driven by heightened health awareness and environmental concerns, leading to increased interest in plant-based diets. Optimizing the production of legume-based stiff dough offers sustainable nutritious options, contributing to food security and public health (Binou *et al.*, 2022). This will encourage industrial application of underutilized legumes and boost local

economies for farmers. In this work, there was individual adjustment of the raw material which used to be only ‘eba’, pounded yam, or ‘fufu’ by blending them with fermented Bambara groundnut flour into various formulations at different ratios.

2.0 Materials and Methods

2.1 Materials

The materials: Bambara groundnut white (*Vigna subterranea* L.) seeds, freshly harvested cassava (*Manihot esculenta*) and yam tubers (*Dioscorea esculenta*), were purchased from Mushin market, Lagos, Nigeria.

2.2 Methods

2.2.1 Processing of Bambara groundnut

Figure 1 presents the flowchart for the processing of Bambara groundnut. The method described by Olapade and Adetuyi (2007) for the processing of beans was adopted with some modifications.

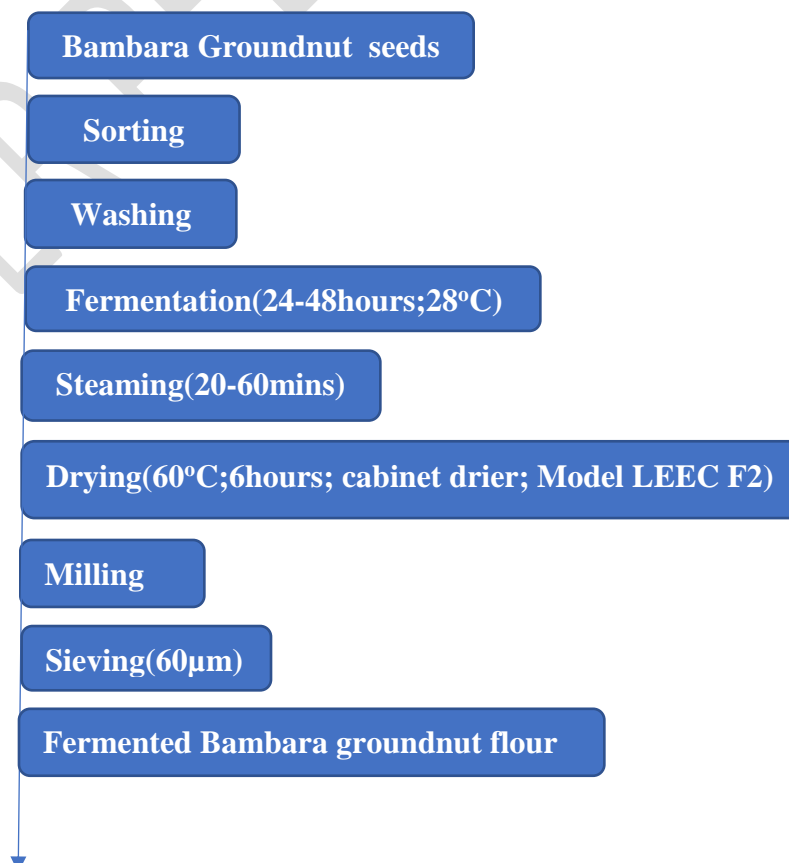


Fig1: Flow chart for the production of fermented Bambara groundnut flour

2.2.2 Processing of yam tubers to instant pounded yam

Figure 2 presents the flowchart for the processing of instant pounded yam. The methods described by Adeola *et al.*, (2012) was adopted with slight modifications.



Fig 2: Flow chart for the production of instant pounded yam

2.2.3 Processing of Cassava to Fufu and Garri

Figure 3 presents the flowchart of cassava processing. The methods described by Babajide *et al.*, 2022 was adopted with slight modification. Cassava roots were peeled, washed, and divided into 2 parts. One part was processed into fufu while the other was processed into Garri.

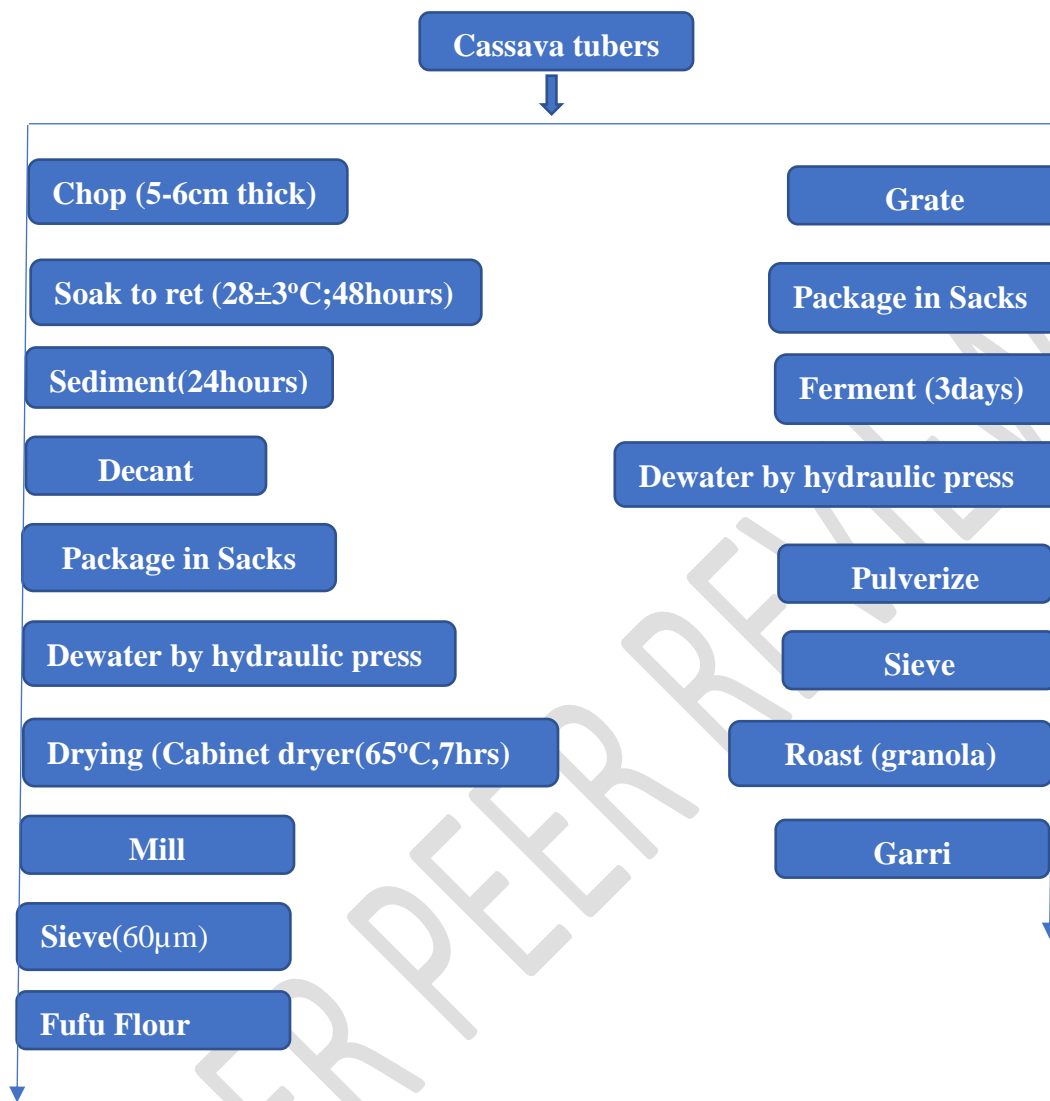


Fig 3: Flow chart for the traditional processing of Cassava to Fufu and Garri

2.2.4 Product Formulation and Preparation

Fermented Bambara groundnut flour produced was blended at different ratios (60:40, 70:30, 80:20, and 90:10) with each of the existing stiff dough flour to obtain a legume-based formula. Preparation of legume-based stiff dough was done by stirring and kneading each legume-base formulation into boiling water.

2.2.5 Sensory Evaluation

Sensory evaluation was carried out according to methods described by Iwe, 2010. Twenty-man panel who are usual consumers of stiff dough were semi-trained as panelists. The stiff dough was rated for color, texture, taste, aroma and general acceptability. The scoring was based on a 9-point hedonic scale ranging from 1 (extremely dislike) to 9 (extremely like) and 5 (neither like nor dislike). The values obtained were subjected to statistical analysis using ANOVA.

2.2.6 Chemical Analysis

Proximate composition analysis (crude protein, crude fiber, total ash, crude fiber, total carbohydrate, fat and moisture content) was carried out according to methods described by AOAC, 2023.

2.2.7 Statistical analysis

Statistical analysis was carried out using SPSS for windows, version 17.0 (SPSS Inc., Chicago, IL). Statistical significance was established using a one-way analysis of variance (ANOVA), and the data was reported as mean values \pm standard deviation (SD). Means were separated using Duncan Multiple range test (DMRT). Significant difference was established at $p < 0.05$.

3.0 Results

3.1 Effect of Process optimization

Figure 4 is a combination of clustered column and line chart which presents the effect of processing on Bambara groundnut seeds. Tannin and protein content were used as benchmark for the quality of the processed legumes. The columns represent processing conditions (fermentation and

steaming) while the lines represent tannin and protein content. It was observed that as fermentation progressed and with increase in steaming time, tannin decreased while protein increased. Increments in protein content peaked after 48 hours fermentation, while the highest percentage loss in tannin content followed the same trend.

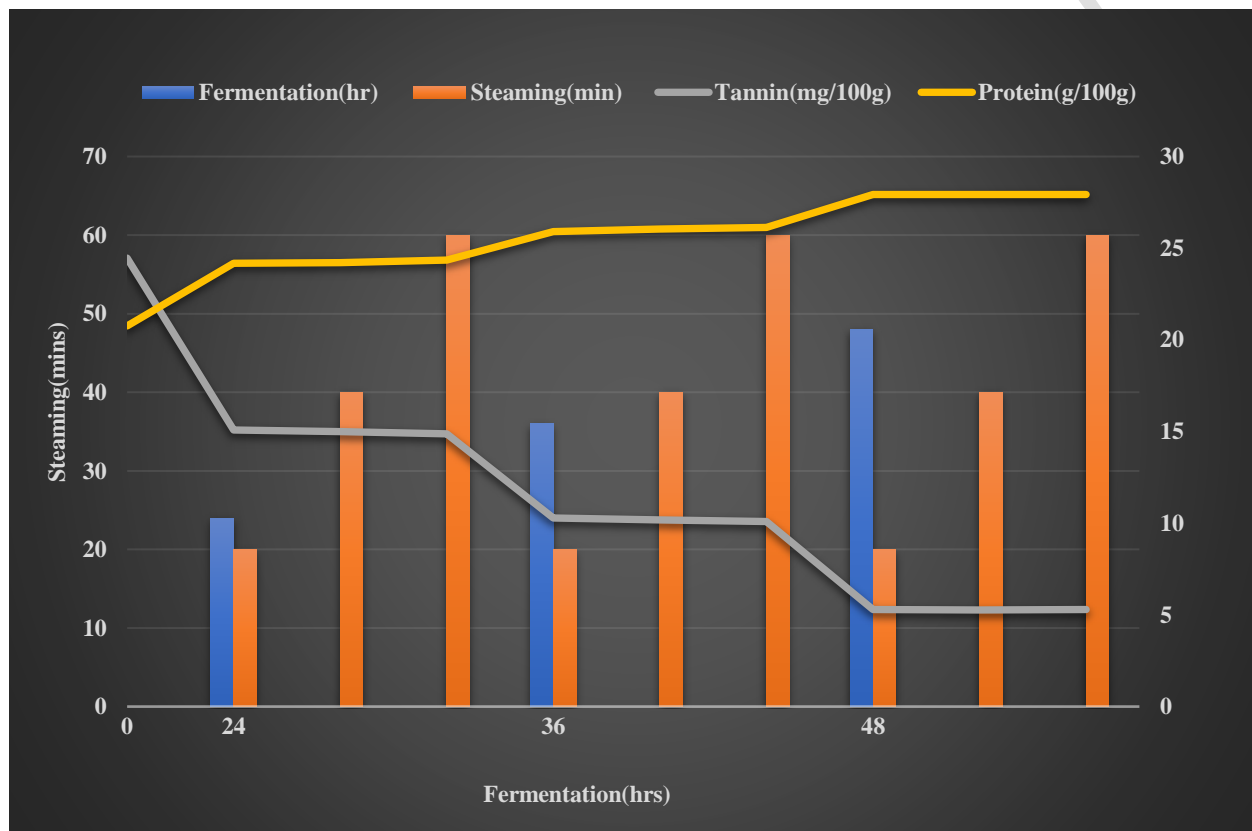


Figure 4: Effect of Processing on the Tannin and Protein content of Bambara Groundnut

3.2 Sensory Evaluation of legume-based stiff dough blends

Table 1 presents sensory evaluation of blends of Bambara groundnut-Eba (BGEB) stiff dough. The color ranged between 6.10 for BGEB90:10 and 8.70 for EB100. There were significant differences ($p < 0.05$) in the color among samples, however, samples EB100 and BGEB60:40 was not significantly different ($p < 0.05$). Texture was characterized by elasticity and moldability. The

texture ranged between 6.10 for BGEB90:10 and 8.60 for EB100. Results indicated significant differences ($p<0.05$) among the samples. Sample BGEB70:30 was most preferred. The taste ranged between 8.30 for BGEB90:10 and 8.50 for EB100. Samples EB100, BGEB60:40 and BGEB70:30 was not significantly different ($p<0.05$). Samples BGEB80:20 and BGEB90:10 was also not significantly different ($p<0.05$) in taste. The aroma ranged between 8.10 for BGEB90:10 and 8.22 for EB100. Samples EB100, BGEB60:40 and BGEB70:30 was not significantly different ($p<0.05$). Samples BGEB80:20 and BGEB90:10 was also not significantly different ($p<0.05$). The overall acceptability ranged between 7.15 for BGEB90:10 and 8.57 for BGEB70:30. Results indicated significant differences ($p<0.05$) among the samples, however, samples EB100 and BGEB60:40 was not significantly different ($p<0.05$). Sample BGEB70:30 ranked highest in overall acceptability.

Table 1: Sensory evaluation of blends of Bambara groundnut-Eba stiff dough

Blending Ratio	Sensory Attributes				
	Color	Texture	Taste	Aroma	Overall Acceptability
EB 100	8.70 ^a ±0.01	8.60 ^c ±0.01	8.50 ^a ±0.01	8.20 ^a ±0.01	8.50 ^b ±0.01
BGEB (60:40)	8.68 ^a ±0.01	8.70 ^b ±0.04	8.48 ^a ±0.04	8.18 ^a ±0.02	8.51 ^b ±0.01
BGEB (70:30)	8.66 ^{ab} ±0.01	8.90 ^a ±0.02	8.48 ^a ±0.02	8.22 ^a ±0.02	8.57 ^a ±0.06
BGEB (80:20)	7.60 ^c ±0.01	7.70 ^d ±0.02	8.30 ^b ±0.02	8.10 ^b ±0.01	7.93 ^c ±0.02
BGEB (90:10)	6.10 ^d ±0.01	6.10 ^e ±0.02	8.30 ^b ±0.01	8.10 ^b ±0.02	7.15 ^d ±0.02

Data=mean ±SD; n=20. Means within a column followed by different letters are significantly different $p<0.05$. Key: EB-Eba; BGEB – Bambara groundnut-Eba

Table 2 presents sensory evaluation of blends of Bambara groundnut-pounded yam (BGPY) stiff dough. The color ranged between 8.78 for BGPY90:10 and 8.80 for PY100. Samples PY100,

BGPY60:40 and BGPY70:30 was not significantly different ($p<0.05$) but at higher concentrations of BGPY80:20 and BGPY90:10 slight significant difference ($p<0.05$) was observed, however, samples BGPY80:20 and BGPY90:10 was not significantly different ($p<0.05$). Texture ranged between 6.10 for BGPY90:10 and 8.90 for BGPY70:30. Results indicated significant differences ($p<0.05$) among the samples. Sample BGPY70:30 was most preferred. The taste ranged between 7.25 for BGPY90:10 and 8.65 for PY100. Results indicated significant differences ($p<0.05$) among samples. Samples PY100, was most accepted. The aroma ranged between 7.12 for BGPY90:10 and 8.40 for PY100. Results indicated significant differences ($p<0.05$) among samples. Sample PY100 was most preferred. The overall acceptability ranged between 7.31 for BGPY90:10 and 8.64 for PY100. Results indicated that samples PY100, BGPY60:40 and BGPY70:30 were not significantly different ($p<0.05$) but differed significantly with samples BGPY90:10 and BGPY80:20, however, samples BGPY90:10 and BGPY80:20 were not significantly different ($p<0.05$).

Table 2: Sensory evaluation of blends of Bambara groundnut-Pounded yam stiff dough

Blending Ratio	Sensory Attributes				
	Color	Texture	Taste	Aroma	Overall Acceptability
PY 100	8.80 ^a ±0.01	8.70 ^c ±0.02	8.65 ^a ±0.02	8.40 ^a ±0.01	8.64 ^a ±0.02
BGPY (60:40)	8.80 ^a ±0.01	8.75 ^b ±0.02	8.60 ^b ±0.01	8.35 ^b ±0.01	8.63 ^a ±0.03
BGPY (70:30)	8.80 ^a ±0.02	8.90 ^a ±0.00	8.55 ^c ±0.02	8.25 ^c ±0.02	8.63 ^a ±0.03
BGPY (80:20)	8.78 ^b ±0.02	8.00 ^d ±0.01	7.32 ^d ±0.01	7.24 ^d ±0.04	7.84 ^b ±0.02
BGPY (90:10)	8.78 ^b ±0.03	6.10 ^e ±0.01	7.25 ^e ±0.02	7.12 ^e ±0.02	7.31 ^c ±0.01

Data=mean ±SD; n=20. Means within a column followed by different letters are significantly different $p<0.05$. Key: PY – Pounded yam; BGPY – Bambara-Pounded yam

Table 3 presents sensory evaluation of Bambara groundnut-fufu (BGFF) stiff dough blends. The color ranged between 7.25 for BGFF90:10 and 8.60 for FF100. Results indicated significant differences ($p<0.05$) among the samples. Texture ranged between 7.25 for BGFF90:10 and 8.36 for BGFF70:30. Results indicated significant differences ($p<0.05$) among the samples. Sample BGFF70:30 was most preferred. The taste ranged between 7.94 for BGFF90:10 and 8.20 for FF100. Results indicated significant differences ($p<0.05$) among samples, however, samples BGFF70:30, BGFF60:40 and FF100 were not significantly different. The aroma ranged between 7.92 for BGFF90:10 and 8.20 for FF100. Results indicated significant differences ($p<0.05$) among samples, however, samples BGFF60:40; BGFF70:30 and FF100 were not significantly different ($p<0.05$). Overall acceptability ranged between 7.59 for BGFF90:10 and 8.25 for FF100. Results indicated significant differences ($p<0.05$) among samples.

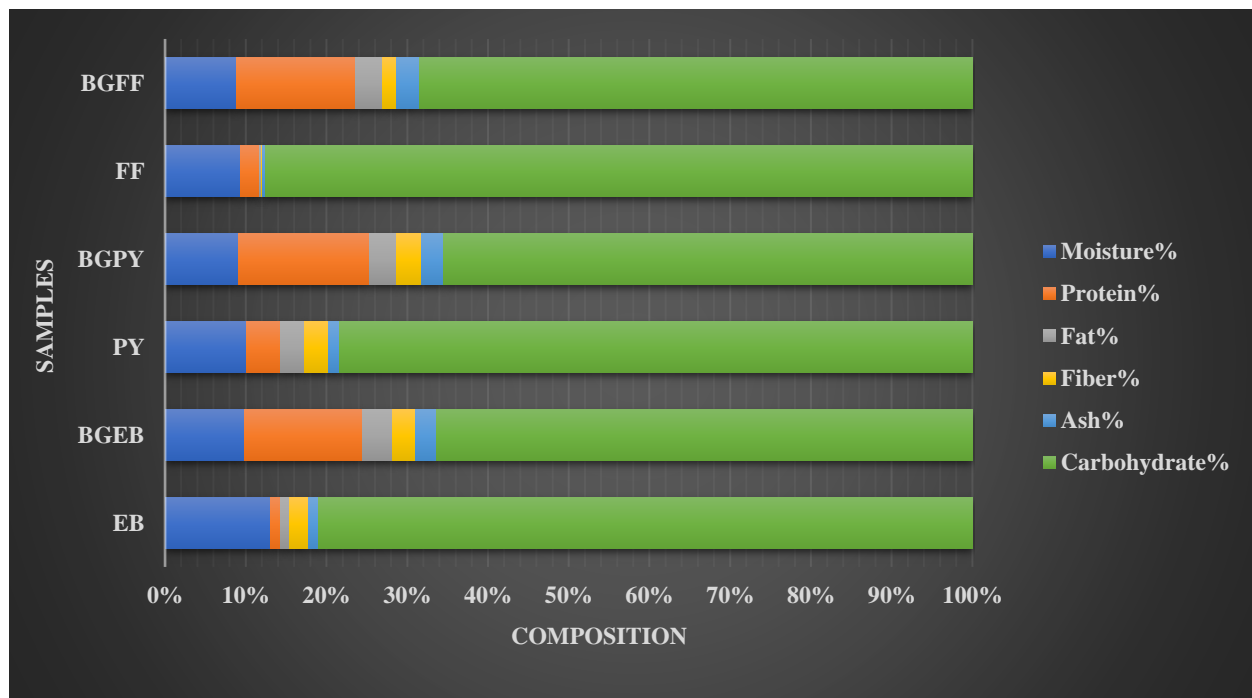
Table 3: Sensory evaluation of blends of Bambara-fufu stiff dough

Blending Ratio	Sensory Attributes				
	Color	Texture	Taste	Aroma	Overall acceptability
FF] 100	8.60 ^a ±0.02	8.00 ^c ±0.01	8.20 ^a ±0.03	8.20 ^a ±0.01	8.25 ^a ±0.02
BGFF (60:40)	8.05 ^b ±0.01	8.22 ^b ±0.01	8.20 ^a ±0.03	8.20 ^a ±0.11	8.17 ^c ±0.01
BGFF (70:30)	8.00 ^b ±0.01	8.36 ^a ±0.01	8.20 ^a ±0.01	8.20 ^a ±0.01	8.19 ^b ±0.01
BGFF (80:20)	7.40 ⁰ ±0.02	7.80 ^d ±0.02	8.02 ^b ±0.01	8.00 ^b ±0.01	7.81 ^d ±0.02
BGFF (90:10)	7.25 ^d ±0.03	7.25 ^e ±0.01	7.94 ^c ±0.02	7.92 ^c ±0.01	7.59 ^e ±0.05

Data=mean ±SD; n=20. Means within a column followed by different letters are significantly different $p<0.05$. Key: FF – Fufu; BGFF – Bambara-Fufu

3.3 Proximate Composition

Figure 5 presents a stacked column chart highlighting proportional difference in the proximate composition of stiff dough flours without Bambara groundnut flour inclusion and stiff dough flours with 70% fermented Bambara groundnut flour inclusion. Moisture content ranged from 9.31% to 13.01% and 8.83% to 9.82%; protein content ranged from 1.31% to 4.24% and 14.63% to 16.26%; fat content ranged from 0.26% to 3.02% and 3.31% to 3.77%; fiber content ranged from 0.17% to 2.90% and 1.64% to 3.12%; ash content ranged from 0.37% to 1.38% and 2.63% to 2.84%; carbohydrate ranged from 78.43% to 87.53% and 65.47% to 68.54% for stiff dough with 0% and 70% fermented Bambara groundnut flour inclusion respectively. Results varied significantly different ($P < 0.05$) among samples.



EB: Eba; BGEB: Bambara-Eba; PY: Pounded yam; BGPY: Bambara-Pounded yam; FF: Fufu; BGFF: Bambara-Fufu.
Figure 5: Proximate composition of stiff dough with 0% and 70% fermented Bambara groundnut flour

3.4 Functional properties of Bambara based stiff dough blends

Table 4 shows the functional properties of the Bambara-based stiff dough. The moisture content ranged between 8.83% for BGFF and 9.82% for BGEB. Results indicate significant difference ($p<0.05$) among samples. The bulk density ranged between 1.54g/cm³ for BGEB and 2.00g/cm³ for BGPY and were not significantly different ($p<0.05$). Swelling capacity ranged between 3ml for BGFF and 11.5ml for BGEB. Results indicated significant difference among samples. Foaming capacity ranged between 4% for BGEB and 8% for BGPY. Results indicated significant difference among samples ($P<0.05$). Foam ability for all samples was not stable. Water absorption capacity ranged between 12% for BGFF and 20% for BGEB and varied significantly different ($p<0.05$) among samples. Oil absorption capacity ranged between 7.4% for BGPY and 8.1% for BGFF. Results indicated significant difference among samples. Emulsion activity ranged between 1.39 for BGEB and 1.47 for BGPY. Results indicate significant difference ($p<0.05$) among samples. Emulsion capacity ranged between 1.47 seconds for BGEB and 4.41 seconds for BGPY. Results indicate significant difference ($p<0.05$) among samples. The least gelation concentration ranged between 8% for BGFF and 22% for BGPY. Results indicated significant difference ($p<0.05$) among samples.

4.0 Discussion

Consumption of stiff dough staples is a deeply rooted cultural dietary practice for Nigerians. Stiff dough is prepared from carbohydrate rich staples. They are rich in calorie but poor in certain key nutrients such as protein. Protein energy malnutrition (PEM) is one of the major burdens of malnutrition worldwide. Diversification into utilization of legumes will improve nutrient composition. Leguminous plants have the potential to play a role in combating food insecurity and malnutrition. However, the possibility of processing it into a stiff dough staple remains a challenge

because of its low gelatinization tendencies and activities of its anti-nutrient compounds. Optimizing process techniques (Fig 4) was designed to improve nutrient quality of the legume prior to product formulation. Fermentation is a desirable process of biochemical modification used to enhance the bio accessibility of nutrients from primary food matrix, as well as improve organoleptic properties and extend shelf life (Kahajdova and Karovicova, 2007; Hotz and Gibson, 2007; Chaves-Lopez *et al.*, 2014). Imperatively reduction of tannin (Fig 4) brought about increases in protein content because tannin has the ability to form complexes with protein which affects digestibility, leading to mal-absorption of proteins. These observations are similar to earlier reports on the effect of processing conditions on anti-nutritional compounds (Udensi and Okoronkwo, 2006; Diouf *et al.*, 2019). Fermentation followed by cooking (boiling) has been reported to be effective in increasing protein digestibility, bringing it nearly to the same level as meat (Osman, 2011), however, in this case steaming(100°C) was applied. Steaming will not only prevent leaching of nutrients into the boiling water which will be discarded but will also inactivate fermentative organisms and heat sensitive antinutritive compounds. Diouf *et al.*, 2019 reported that a combination of steaming with other techniques could be a good track for reducing anti-nutritional compounds while retaining nutritional and organoleptic qualities of the final product.

The best formulation ratio was determined by results obtained from sensory evaluation. This is the highest ratio that will not compromise traditional quality patterns. These are patterns which have been strongly linked to a territory; have historical depth and have been passed from generation to generation. Results revealed that 70% fermented Bambara groundnut flour inclusion was most accepted. Attaining 70% inclusion could be attributed to the processing conditions applied which would have affected the flour matrixes improving hydrophobic interactions. Fermentation reduced anti-nutritional contents and increased protein content. Proteins in food in addition to providing

nutrition possess functional properties. Denatured proteins improve viscoelasticity and gelatinization properties. The blend in taste, aroma and color for some of the samples could be attributed to the fact that most of the flour were fermented during processing; and the fermented Bambara groundnut flour which was cream colored was close to the color of the existing stiff dough.

Proximate composition of the developed legume-based stiff dough (70% fermented Bambara groundnut flour inclusion) showed significantly improved nutrient content with protein content rising above 50%. It is evident that the fermented Bambara groundnut flour is the major source of protein in the composite flour blends. This confirms to earlier report by Fashakin *et al.*, (1986) on the beneficial effects of vegetable protein supplementation. Increased protein could also be attributed to microbial degradation of anti-nutrients; activities of hydrolytic enzymes; the degradation of complex proteins to amino acids through proteolysis as well as increased biomass (Akubor and Chukwu 1999; Difo *et al.*, 2014). Increase in fat content could be attributed to breakdown of lipids by lipase (Adebowale and Maliki 2011). Increased ash content could be due to the metabolic activities of the fermenting organism which hydrolyze the metal-phytate complexes improving its availability. Increase in fiber may be due to the degrading activity of cellulase on cellulose/hemicellulose from the fermentative micro biome (Onoja and Obizoba, 2009; Granito *et al.*, 2002).

The variations observed in the functional properties can be attributed to several factors, including differences in water absorption rates and swelling behavior of starch granules during heating (Ragae and Abdel-Aal, 2006). These factors are influenced by the specific legume varieties used in the blends and their processing methods. Bulk density is an important consideration for packaging and handling of products. While a higher bulk density might intuitively suggest less

packaging space required, Agunbiade and Ojezele (2010) reported that lower bulk density actually necessitates more packaging volume. This is relevant when considering the efficient transportation and storage of the legume-based stiff dough blends. Water absorption capacity (WAC) is a crucial functional property influencing the reconstitution and texture of stiff dough products. High WAC indicates a better ability of the flour blend to absorb water, leading to improved dough formation and final product quality (Uwaegbute *et al.*, 2000). This is particularly important in stiff doughs, where proper hydration is essential for achieving the desired consistency. Proteins and carbohydrates, abundant in legumes, are the primary components responsible for WAC due to their hydrophilic nature, possessing polar or charged side chains that attract water molecules (Chandra *et al.*, 2015). The developed legume-based blend is rich in both protein and carbohydrates, suggesting a favorable WAC. Oil absorption capacity (OAC) plays a role in the ability of the flour components, primarily starch, to physically bind fat through capillary attraction. However, as observed in this study, increased fat content within the flour blends may have led to a reduced capacity to absorb or retain additional oil (Kinsella, 1976). This could be attributed to the saturation of binding sites within the flour matrix. Emulsion properties are also significant in food systems. Emulsion activity and capacity, which describe the ability of proteins to interact with and emulsify oil, respectively, are influenced by both oil and protein concentrations (Sikorski, 2002). The observed emulsion activity in the legume-based blend suggests the nature of protein-fat interactions within the system. Gelation, the process of forming a three-dimensional network that traps water, is a key functional property for stiff doughs. The least gelation concentration (LGC) serves as an indicator of gelation capacity; a lower LGC signifies a stronger gelling ability (Akintayo *et al.*, 1999) and is a desirable protein functionality advantage in legume-based stiff

dough applications, contributing to texture and structure (Adesola *et al.*, 2025). The Bambara-fufu blend therefore demonstrates potential as a gel-forming additive in food products.

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Table 4: Functional Properties of Bambara groundnut-based flour blends

Samp le	Moistu re (%)	Bulk densi ty (g/cm³)	Swelli ng capaci ty (ml)	Foam capaci ty (%)	Foam stabili ty (%)	Water absorpti on capacity (%)	Oil absorptio n capacity(%)	Emulsi on activity	Emulsi on stabilit y (secs)	Gelation temperature(°C)	Least Gelation concentration (%)
BGE	9.82 ^b	1.54 ^a	11.50 ^a	4.00 ^c	0	20.00 ^a	7.80 ^b	1.39 ^c	1.47 ^{bc}	103°C ^{ab} ±0.01	18.00 ^b
B	±0.02	±0.01	±0.01	±0.01		±0.01	±0.01	±0.01	±0.01		±0.01
BGP	9.10 ^a	2.00 ^a	8.50 ^b	8.00 ^a	0	14.00 ^b	7.40 ^c	1.47 ^a	4.41 ^a	101°C ^a	22.00 ^a
Y	±0.01	±0.01	±0.01	±0.01		±0.01	±0.01	±0.01	±0.01	±0.00	±0.01
BGF	8.83 ^b	1.91 ^a	3.00 ^c	6.00 ^b	0	12.00 ^c	8.10 ^a	1.43 ^b	1.53 ^b	100°C ^a	8.00 ^c
F	±0.01	±0.01	±0.01	±0.01		±0.01	±0.01	±0.01	±0.00	±0.01	±0.01

Data=mean ±SD; n=3; Means within a row followed by different letters are significantly different p<0.05. BGEB-Bambara-Eba; BGPY-Bambara-yam; BGFF-Bambara-Fufu.

5.0 Conclusion

Blending 70% fermented Bambara groundnut flour into selected stiff dough staples offers a pathway to nutrient-dense, health-promoting diets, as demonstrated by this study. This innovative approach to traditional food systems promotes dietary diversification, offers a potential fortification strategy against malnutrition, optimizes local agricultural resources, and encourages consumption of improved local staples, reducing reliance on imported processed foods. This contributes to sustainable food systems and aligns with Sustainable Development Goals 2 (Zero Hunger), 9 (Industry, Innovation, and Infrastructure), and 12 (Responsible Consumption and Production).

Disclaimer (Artificial intelligence)

Option 1:

Authors hereby declare that NO generative AI technologies such as large language models (ChatGPT, COPILOT, etc) and text-to-image generation have been used during the writing or editing of this manuscript.

References

- Adebowale, O. J. & Maliki, K. (2011). Effect of fermentation period on the chemical composition and functional properties of pigeon pea (*Cajanus cajan*) seed flour. *Int. Food Res. J.*, 18, 1329–1333. [Google Scholar]
- Adeola, A. A., Otegbayo, B. O. & Ogunnoiki, S. (2012). Preliminary Studies on the Development and Evaluation of Instant Pounded Yam from *Dioscorea alata*. *J. Appl. Sci. Environ. Management* 16(3 287-290)
- Adesola, M. O., Adejuyitan, J. A. & Idowu, O.O. (2021). “Effect of Co-Fermentation of Cassava and African Yam Bean on Some Compositional and Sensory Properties of Pupuru”. *Journal of Scientific Research and Reports* 27 (8):29-35. <https://doi.org/10.9734/jsrr/2021/v27i830421>

Agbenorhevi, J. K., Oduro, I., Ellis, W. O., Aodakpi, V. D., & Eleblu, S. E. (2007). Effect of soaking, autoclaving and repeated boiling on oligosaccharides in cowpea. *Nigerian Food Journal*, 25(2), 88–94. [Google Scholar]

Agunbiade S. O. & Ojezele M. O. (2010). Quality evaluation of instant breakfast cereals fabricated from maize, sorghum, soybean and African yam bean (*Sphenostylis stenocarpa*). *World J. Dairy and Food Sci.* 5: 7-72.

Akintayo, E. T., Oshodi A. A. & Esuoso, K. O. (1999). Effects of NaCl, Ionic strength and pH on the foaming and gelation of pigeon pea (*Cajanus cajan*) protein concentrations. *Food Chemistry* 66:51-56.

Akinwande, B. A., Abiodun, O. A., Adeyemi, I. A. & Akanbi, C. T. (2008). Effect of steaming method and time on the physical and chemical properties of flour from yam tubers. Available online www.ajol.info/journals/nifo

Akubor, P. I. & Chukwu, J. K. (1999). Proximate composition and selected functional properties of fermented and unfermented African oil bean (*Pentaclethra macrophylla*) seed flour. *Plant Foods Hum. Nutr.* 54, 227–238. [Google Scholar] [CrossRef] [PubMed]

Aschemann-Witzel, J., Gantriis, R. F., Fraga, P., & Perez-Cueto, F. J. A. (2020). Plant-based food and protein trend from a business perspective: markets, consumers, and the challenges and opportunities in the future. In *Critical Reviews in Food Science and Nutrition* (pp. 1–10). Taylor and Francis Inc. <https://doi.org/10.1080/10408398.2020.1793730>

Association of Official Analytical Chemists (AOAC). Official methods of analysis. 22nd Edition. Washington DC, USA.

Babajide K., & Ironidi, Emmanuel & Alamu, Emmanuel & Ajani, Emmanuel & Abass, Adebayo & Adesokan, Michael & Parkes, Elizabeth & Maziya-Dixon, Busie. (2022). Influence of traditional processing and genotypes on the antioxidant and antihyperglycaemic activities of yellow-fleshed cassava. *Frontiers in Nutrition*. 9. 10.3389/fnut.2022.894843.

Binou, P., Yanni, A. E. & Karathanos, V. T. (2022). Physical properties, sensory acceptance, postprandial glycemic response, and satiety of cereal-based foods enriched with legume flours: a review. *Crit Rev Food Sci Nutr.* 2022;62(10):2722-2740. doi: 10.1080/10408398.2020.1858020. Epub 2020 Dec 11. PMID: 33305591.

Brand-Miller, J., Hayne, S., Petocz, P. & Colagiuri, S. (2003). Low-glycemic index diets in the management of diabetes: a meta-analysis of randomized controlled trials. *Diabetes Care*: 26:2261–7. doi: 10.2337/diacare.26.8.2261. [DOI] [PubMed] [Google Scholar]

Chandra, S., Singh, S. & Kumari, D. (2015). Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuit. *Journal of Food Science and Technology*, 52, 3681-3688.

Chaves-Lopez, C., Serio, A., Grande-Tovar, C. D., Cuervo-Mulet, R., Delgado-Ospina, J. & Paparella, A. (2014). Traditional fermented foods and beverages from a microbiological and

nutritional perspective: The Colombian Heritage. *Comprehensive Reviews in Food Science and Food Safety*, 13, 1031-1048.

Difo, H. V. Onyike, E. Ameh, D. A. Ndidi, U. S. & Njoku, G. C. (2014). Chemical changes during open and controlled fermentation of cowpea (*Vigna unguiculata*) flour. *Int. J. Food Nutr. Saf.*, 5, 1–10. [Google Scholar]

Diouf, A., Sarr, F., Sene, B., Ndiaye, C., Fall, S. & Ayessou, N. (2019). Pathways for reducing anti-nutritional factors: prospects for *Vigna unguiculata*. *Journal of Nutritional Health & Food Science*, 7 (2) pp. 1-10, 10.15226/jnhfs.2019.001157

Fashakin, J. B., Awoyefa., M. B. & Furst, P. (1986). The application of protein concentrates from locally available legumes in development of weaning food. *Journal of Nutritional Science Ernahrungswisse* 25: 220-227.

Gibson, R. S., Kafwembe, E., Mwanza, S., Gosset, L., Bailey, K. B., Mullen, A., Baisley, K. & Filteau, S. (2011). A micronutrient-fortified food enhances iron and selenium status of Zambian infants but has limited efficacy on zinc. *J Nutr.*;141(5):935–943. doi:10.3945/jn.110.135228. [DOI] [PubMed] [Google Scholar]

Granito, M., Frias, J., Doblado, R., Guerra, M., Champ, M. & Vidal-Valverde, C. (2002). Nutritional improvement of beans (*Phaseolus vulgaris*) by natural fermentation. *Eur. Food Res. Technol.* 214, 226–231. [Google Scholar] [CrossRef]

Hotz, C., & Gibson, R. S. (2007). Traditional food-processing and preparation practices to enhance the bioavailability of micronutrients in plants-based diets. *Journal of Nutrition*, 137,1097-1100.

Iwe, M. (2010). Handbook of Sensory Methods and Analysis. Rojoint Communication Services Ltd. Enugu. 75-78.

Kahajdova, Z. and Karovicova, J. (2007). Fermentation of cereals for specific purpose. *Journal of Food and nutrition Research*, 46, 51-57.

Kinsella, J. E. (1976). Functional properties of protein in food – A survey. *Crit. Rev. Food Sci. Nutr.* 5:219.

Linnemann, A. R., (1988). “Cultivation of Bambara groundnut in Northern Nigeria” Tropical Crops and Communications, vol. 15, pp. 1– 14.

Messina V. (2014). Nutritional and health benefits of dried beans. *Am J Clin Nutr.* 100 Suppl 1:437S-42S. doi: 10.3945/ajcn.113.071472. Epub. PMID: 24871476.

Michaelsen, K. F., Hoppe, C., Roos, N., Kaestel, P., Stougaard, M., Lauritzen, L., Mølgaard, C., Girma, T. & Friis, H. (2009). Choice of foods and ingredients for moderately malnourished children 6 months to 5 years of age. *Food and Nutrition Bulletin*, vol. 30, no. 3 © 2009 (supplement), The United Nations University.

Odunfa, S. A. (1998). Cassava to garri. *Nig. J. Sci. and Technol.*, 1:186-189.

Olapade, A. & Adetuyi, D. O., (2007). Comparison of different methods of producing Bambara (*Voandzeia subterranean* L. Thou) flours for preparation of ‘moimoi’, *Nigerian Food Journal*, pp.150 – 157.

Onoja, U. S. & Obizoba, I. C. (2009). Nutrient composition and organoleptic attributes of gruel based on fermented cereal, legume, tuber and root flour. *Agro-Sci. J. Trop. Agric. Food Environ. Ext.*, 8, 162–168. [Google Scholar] [CrossRef] [Green Version]

Osman, M.A. (2011). Effect of traditional fermentation process on the nutrient and antinutrient contents of pearl millet during preparation of *Lohoh*. *J. Saudi Soc. Agric. Sci.* 10, 1–6. [Google Scholar] [CrossRef] [Green Version].

Ragae, S. & Abdel-Aal, E. M. (2006). Pasting properties of starch and protein in selected cereals and quality of their food products. *Food Chemistry* 95: 9-18.

Sikoriski, Z. E. (2002). Chemical and functional properties of food components. Sikoriski (Ed.). Florida: CRC Press, Inc. pp. 133-178.

Udensi, E A. and Okoronkwo, K. A. (2006). Effects of fermentation and germination on the physicochemical properties of *Mucuna cochinchinesis* protein isolate. *African Journal of Biotechnology* 5(10):896-900.

Uwaegbute, A. C., Iroegbu, C. U. & Eke, O. (2000). Chemical and sensory evaluation of germ cowpeas (*Vigna unguiculata*) and their products. *Fd Chem.* 68:141-146.

World Health Organization, (2002). Diet, nutrition, and the prevention of chronic diseases. Report of a WHO Study Group. Geneva, Switzerland.