

Sprouted Kidney Bean–Plantain Stiff Meal: Unlocking Nutritional, Glycemic Potential and Phytohaemagglutinin Properties

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ABSTRACT

Sprouted Kidney bean (*Phaseolus vulgaris*) is a nutrient-dense legume containing substantial amounts of protein, dietary fibre, minerals and bioactive compounds. Incorporating kidney bean flour into plantain-based products can complement the nutritional limitations of plantain flour by increasing protein and fibre contents and improving the overall nutrient density of the food. This study investigated the nutritional, functional, phytochemical, antioxidant, glycemic, anti-nutritional and sensory characteristics of stiff meal produced from sprouted kidney bean and unripe plantain flour blends. Five formulations were developed: A (100% unripe plantain flour), B (20% sprouted kidney bean flour + 80% plantain flour), C (30% sprouted kidney bean flour + 70% plantain flour), D (50% sprouted kidney bean flour + 50% plantain flour), and E (100% sprouted kidney bean flour). The flour blends and resulting stiff meals were evaluated for proximate composition, mineral profile, functional properties, physicochemical and pasting characteristics, colour attributes, anti-nutritional factors, qualitative and quantitative phytochemicals, antioxidant activity, phytohemagglutinin (PHA), glycemic index (GI), glycemic load (GL) and sensory acceptability. Increasing sprouted kidney bean incorporation enhanced protein, fibre, ash, selected mineral contents, water and oil absorption capacities, phytochemical constituents and antioxidant activity, while reducing carbohydrate content and altering the pasting and colour characteristics of the products. The incorporation of sprouted kidney bean also influenced the anti-nutritional profile and PHA content of the formulations. Glycemic response showed a progressive reduction with increasing sprouted kidney bean substitution, indicating improved glycemic characteristics compared with the 100% plantain formulation. Sensory evaluation showed that the composite stiff meals remained generally acceptable, although higher levels of bean incorporation produced greater changes in colour, aroma, taste and texture. Overall, the findings demonstrate that sprouted kidney bean–unripe plantain flour blending can be used to develop a nutrient-enriched stiff meal with favorable functional and glycemic characteristics and potential application as a lower-glycemic traditional food.

Keywords: Sprouted kidney bean; unripe plantain; stiff meal; glycemic index; phytohemagglutinin; functional food.

INTRODUCTION

The increasing prevalence of diet-related metabolic disorders has heightened interest in the development of functional foods that combine nutritional adequacy with favourable glycemic characteristics. In many developing countries, traditional staple foods remain important sources of dietary energy but are often dominated by carbohydrates. Improving the nutritional quality of such staples through the incorporation of nutrient-rich plant materials may provide a practical approach to addressing nutritional deficiencies while retaining culturally familiar foods (Los *et al.*, 2018; Dibakoane *et al.*, 2023).

Unripe plantain (*Musa paradisiaca*) is an important tropical food crop widely consumed in West Africa. Its flour is rich in starch and contains dietary fibre and resistant starch, characteristics that may influence starch digestibility and postprandial glucose response. Unripe plantain flour is therefore a promising ingredient for the

development of foods with potentially favourable glycemic properties. However, its relatively low protein content limits its ability to provide a balanced nutritional profile when used as the sole major ingredient (Dibakoane *et al.*, 2023; Oladele & Williamson, 2016).

Kidney bean (*Phaseolus vulgaris*) is a nutrient-dense legume containing substantial amounts of protein, dietary fibre, minerals and bioactive compounds. Incorporating kidney bean flour into plantain-based products can complement the nutritional limitations of plantain flour by increasing protein and fibre contents and improving the overall nutrient density of the food. In addition, kidney beans contain phenolic compounds, flavonoids and other phytochemicals that may contribute to antioxidant activity (Los *et al.*, 2018; Yang *et al.*, 2018)

However, the presence of anti-nutritional factors, particularly lectins such as phytohaemagglutinin (PHA), requires adequate processing before consumption (Zhang *et al.*, 2023; Shimelis & Rakshit, 2007)

Sprouting is a traditional and increasingly studied processing technique that can modify the nutritional, functional and bioactive properties of legumes. During germination, metabolic and enzymatic activities can alter protein, carbohydrate, phytochemical and anti-nutritional components. The subsequent thermal processing of sprouted kidney beans may further influence compounds such as PHA. Thus, combining sprouting with appropriate cooking may provide an opportunity to improve the nutritional and functional characteristics of kidney bean-based food products while addressing important food-safety considerations (Srenuja *et al.*, 2023; Tuncel *et al.*, 2025; Shimelis & Rakshit, 2007).

The development of composite flour products from legumes and plantain is particularly relevant because blending can produce complementary nutritional and technological properties. The interaction between kidney bean components and plantain starch may affect water absorption, swelling, pasting behaviour, texture, colour and overall acceptability. Furthermore, increased protein and dietary fibre contents and changes in starch characteristics may influence the glycemic response of the resulting food (Los *et al.*, 2018; Adeoye *et al.*, 2025).

Stiff meal is a culturally important staple food in Nigeria and other parts of West Africa. Despite its widespread consumption, there is limited information on the development of stiff meal from sprouted kidney bean and unripe plantain flour blends, particularly regarding the combined effects of formulation on nutritional composition, functional characteristics,

phytochemical profile, antioxidant capacity, anti-nutritional factors, phytohaemagglutinin, glycemic properties and consumer acceptability. Addressing these gaps could contribute to the development of a nutritionally improved traditional food with potential application in diets requiring favourable glycemic characteristics (Adeoye *et al.*, 2025; Srenuja *et al.*, 2023).

Therefore, this study aimed to develop and characterize stiff meal produced from sprouted kidney bean and unripe plantain flour blends. The study evaluated the proximate and mineral composition, functional properties, physicochemical and pasting characteristics, colour attributes, anti-nutritional factors, phytohaemagglutinin content, qualitative and quantitative phytochemicals, antioxidant activity, glycemic index, glycemic load and sensory properties of the resulting stiff meals. The study further sought to identify a formulation that provides a desirable balance between nutritional enhancement, functional quality, glycemic characteristics and sensory acceptability.

MATERIALS AND METHOD

Materials and Experimental Design

Mature, sound kidney bean (*Phaseolus vulgaris* L.) seeds and unripe plantain (*Musa* spp.) were used for the production of sprouted kidney bean–plantain composite flour. The raw materials were obtained from a local market in Nigeria. Analytical-grade reagents were used for the chemical, phytochemical, antioxidant, anti-nutritional and other laboratory analyses.

Five formulations were prepared based on the proportion of sprouted kidney bean flour (SKB) and unripe plantain flour (PF): A (100% PF), B (20% SKB + 80% PF), C (30% SKB + 70% PF), D (50% SKB + 50% PF), and E (100% SKB). Sample A served as the control.

All laboratory analyses were conducted in triplicate, and the results were expressed as mean $\pm$ standard deviation.

Preparation of Unripe Plantain Flour

Unripe plantain fingers were sorted to remove damaged and diseased fruits, washed thoroughly, peeled and sliced into uniform pieces. The slices were oven-dried at approximately 60 °C until constant weight was achieved. The dried plantain slices were cooled, milled into flour and sieved to obtain a relatively uniform particle size. The resulting plantain flour was packaged in airtight polyethylene bags and stored under suitable conditions until use.

Preparation of Sprouted Kidney Bean Flour

Kidney bean seeds were manually sorted to remove stones, broken seeds, discoloured seeds and other foreign materials. The cleaned seeds were washed and soaked in potable water for approximately 12 h. After soaking, the water was drained and the seeds were rinsed and spread on clean, moist trays.

The seeds were allowed to germinate under ambient conditions for approximately 48 h, with periodic moistening to maintain adequate moisture. Following germination, the sprouted beans were oven-dried at approximately 50–60 °C until constant weight was attained. The dried sprouts were cooled, milled and sieved. The resulting sprouted kidney bean flour was stored in airtight containers until formulation.

Preparation of Composite Flour Blends

The plantain and sprouted kidney bean flours were weighed according to the five predetermined formulations:

Sample	Sprouted Kidney Bean Flour (%)	Unripe Plantain Flour (%)
A (PF)	0	100
B (SBPF1)	20	80
C (SBPF2)	30	70
D (SBPF3)	50	50
E (SB)	100	0

The individual flours were thoroughly mixed to obtain homogeneous composite flour samples. Each formulation was appropriately coded and stored in airtight containers prior to analysis and stiff-meal preparation. These are the formulations actually used in the reported results.

Preparation of Stiff Meal

Stiff meal was prepared from each flour formulation using a standardized cooking procedure. A measured quantity of water was brought to boiling, after which a portion of the flour was mixed with water to form a smooth slurry. The slurry was gradually introduced into the boiling water with continuous stirring.

The remaining flour was gradually added while stirring continuously until a smooth and cohesive dough was obtained. The mixture was cooked for approximately 5–10 min with intermittent stirring to ensure adequate cooking and starch gelatinization. The resulting stiff meals were portioned into clean containers and used immediately for sensory evaluation and other analyses requiring cooked samples.

Proximate Composition

Moisture, ash, crude protein, crude fat and crude fibre contents of the flour and stiff-meal samples were

determined using standard AOAC procedures. Carbohydrate content was calculated by difference:

$$\text{Carbohydrate (\%)} = 100 - [\text{Moisture} + \text{Ash} + \text{Protein} + \text{Fat} + \text{Fibre}]$$

Energy value was estimated using the Atwater conversion factors:

$$\text{Energy (kcal/100 g)} = (4 \times \text{protein}) + (9 \times \text{fat}) + (4 \times \text{carbohydrate}).$$

The reported formulations showed progressive increases in protein, fibre and ash with increasing sprouted kidney bean incorporation, while carbohydrate content decreased.

Mineral Composition

Mineral composition was determined following appropriate acid digestion of the samples. Calcium, magnesium, iron and zinc were determined using an appropriate spectrometric method, while sodium and potassium were determined using suitable instrumental procedures.

The mineral concentrations were expressed as mg/100 g sample. The minerals assessed included calcium, magnesium, potassium, sodium, iron, zinc and phosphorus.

Functional Properties

The functional properties of the flour blends were evaluated based on bulk density, water absorption capacity, oil absorption capacity, swelling capacity, solubility, dispersibility, foaming capacity and emulsifying capacity using established analytical procedures.

These parameters were determined to assess the influence of increasing sprouted kidney bean incorporation on the hydration, dispersion and processing characteristics of the composite flours.

Physicochemical Properties

The pH of each sample was determined using a calibrated digital pH meter following preparation of an appropriate aqueous suspension. Titratable acidity was determined by titration against standardized sodium hydroxide solution and expressed as percentage acidity.

Water activity was determined using a calibrated water-activity meter under controlled conditions.

Pasting Properties

Pasting characteristics of the flour blends were determined using a Rapid Visco Analyzer (RVA). The flour samples were dispersed in distilled water according to the manufacturer's recommended sample-to-water ratio and subjected to a controlled heating and cooling cycle.

The parameters determined included peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time and pasting temperature. The results showed progressive changes in these parameters with increasing sprouted kidney bean incorporation.

Colour Characteristics

The colour characteristics of the stiff meals were determined using a calibrated colourimeter based on the CIE Lab* colour system.

The **L*** value represented lightness, **a*** represented redness/greenness and **b*** represented yellowness/blueness. Chroma and hue angle were also determined where applicable.

Determination of Anti-Nutritional Factors

The anti-nutritional factors evaluated included phytate, oxalate, tannins, saponins, trypsin inhibitor activity and cyanogenic glycosides.

Phytate and oxalate were determined using appropriate standard analytical procedures, while tannins and other phytochemicals were quantified using validated spectrophotometric methods. Trypsin inhibitor activity was determined using an enzymatic assay based on inhibition of trypsin activity.

The results were expressed in appropriate units per 100 g or per gram of sample, depending on the parameter.

Determination of Phytohaemagglutinin

Phytohaemagglutinin (PHA) activity was determined because of its importance as a food-safety parameter in kidney bean products.

An extract of each sample was prepared and serially diluted before being tested for haemagglutination activity using suitable erythrocytes. The highest dilution showing visible agglutination was recorded as the haemagglutination titre and expressed as haemagglutinating units per gram (HU/g).

PHA was determined for the different formulations to assess the effect of increasing sprouted kidney bean incorporation and subsequent cooking on lectin activity. The reported results showed an increase in PHA with increasing bean incorporation.

Qualitative Phytochemical Screening

Qualitative phytochemical screening was performed on extracts of the samples to determine the presence or absence of major secondary metabolites. The phytochemicals assessed included alkaloids, flavonoids, tannins, saponins, phenols, terpenoids, steroids, glycosides, phytates and related compounds.

The results were recorded based on the characteristic reactions observed for each phytochemical constituent.

Quantitative Phytochemical Analysis

Total phenolic content was determined using the Folin–Ciocalteu colorimetric method and expressed as mg gallic acid equivalents (GAE)/100 g sample.

Total flavonoid content was determined using an aluminum chloride colorimetric assay and expressed as mg quercetin equivalents (QE)/100 g sample.

Quantification was also performed for selected phytochemicals including tannins, saponins and alkaloids using appropriate validated analytical procedures. The results demonstrated increased phytochemical concentrations with increasing incorporation of sprouted kidney bean flour.

Antioxidant Activity

The antioxidant potential of the samples was evaluated using established in-vitro antioxidant assays, including DPPH radical-scavenging activity, ABTS radical-scavenging activity, ferric-reducing antioxidant power (FRAP) and total antioxidant capacity.

For DPPH analysis, the sample extract was reacted with DPPH solution and the decrease in absorbance was measured spectrophotometrically. Radical-scavenging activity was calculated as:

$$\text{DPPH inhibition (\%)} = [(A_0 - A_1)/A_0] \times 100$$

where A_0 represents the absorbance of the control and A_1 represents the absorbance of the sample.

The antioxidant results were compared with the total phenolic and flavonoid contents to assess their possible contribution to antioxidant activity.

Determination of Glycemic Index

The glycemic index (GI) of the stiff meals was determined using a standardized available-carbohydrate portion and an appropriate reference food. Participants fasted overnight before consumption of the test and reference foods on separate occasions.

Capillary blood glucose was measured at baseline and at predetermined intervals following consumption. The incremental area under the glucose-response curve (IAUC) was calculated, excluding areas below the baseline.

The glycemic index was calculated as:

$$\text{GI} = (\text{IAUC of test food} / \text{IAUC of reference food}) \times 100$$

The reported results showed a progressive decrease in GI from 95.61 for the 100% plantain formulation to 84.36, 76.08 and 65.80 for the 20, 30 and 50% sprouted kidney bean formulations, respectively, while the 100% sprouted kidney bean sample recorded 56.82.

Where human participants are involved, ethical approval and informed consent must be obtained before commencement of the study.

Determination of Glycemic Load

Glycemic load was calculated using the glycemic index and available carbohydrate content of the specified serving:

$$\text{GL} = (\text{GI} \times \text{available carbohydrate per serving})/100$$

The GL values were used to estimate the potential glycemic impact of each stiff-meal formulation. The reported GL decreased progressively from 76.47 in the control to 45.08 in the 50% sprouted kidney bean formulation and 34.52 in the 100% sprouted kidney bean sample.

Sensory Evaluation

Sensory evaluation was conducted using adult panelists familiar with stiff-meal products. The samples were coded using three-digit random numbers and presented under standardized conditions.

The attributes evaluated included appearance, colour, aroma, taste, texture, mouthfeel and overall acceptability. A 9-point hedonic scale ranging from 1 = dislike extremely to 9 = like extremely was used.

The reported overall acceptability scores were 8.12, 7.86, 7.64, 7.38 and 6.82 for samples A, B, C, D and E, respectively.

Statistical Analysis

All experimental determinations were performed in triplicate and results were expressed as mean $\pm$ standard deviation. Data were subjected to one-way analysis of variance (ANOVA) to determine significant differences among the formulations.

Where significant differences occurred, mean separation was performed using an appropriate post-hoc multiple-comparison test. Statistical significance was accepted at $p < 0.05$.

Pearson correlation analysis was performed where appropriate to assess relationships among nutritional composition, phytochemical content, antioxidant activity and glycemic characteristics

RESULT

Sample Code	FORMULATION
A (PF)	100% Plantain Flour
B (SBPF1)	20% SB +80%PF
C (SBPF2)	30% SB +70%PF
D (SBPF3)	50% SB +50%PF
E (SB)	100% Sprouted Kidney Bean

A = 100% plantain; B = 20:80; C = 30:70; D = 50:50; E = 100% sprouted kidney bean.

Table 1. Proximate composition

Sample	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fibre (%)	Carbohydrate (%)	Energy (kcal/100 g)
A (PF)	7.84 ± 0.12 ^a	2.61 ± 0.08 ^a	5.82 ± 0.16 ^a	1.42 ± 0.07 ^a	2.31 ± 0.11 ^a	79.99 ± 0.25 ^c	354.86 ± 1.12 ^a
B (SBPF1)	7.67 ± 0.15 ^a	2.83 ± 0.06 ^{ab}	9.14 ± 0.21 ^b	1.71 ± 0.05 ^{ab}	3.02 ± 0.13 ^b	75.63 ± 0.31 ^d	353.77 ± 1.35 ^a
C (SBPF2)	7.51 ± 0.10 ^a	3.02 ± 0.09 ^b	10.68 ± 0.18 ^c	1.93 ± 0.06 ^b	3.47 ± 0.12 ^c	73.39 ± 0.28 ^c	353.65 ± 1.09 ^a
D (SBPF3)	7.36 ± 0.13 ^a	3.38 ± 0.07 ^c	14.27 ± 0.24 ^d	2.34 ± 0.08 ^c	4.16 ± 0.15 ^d	68.49 ± 0.36 ^b	352.30 ± 1.27 ^a
E (SB)	7.18 ± 0.11 ^a	3.76 ± 0.10 ^d	20.41 ± 0.27 ^c	2.86 ± 0.09 ^d	5.02 ± 0.14 ^c	60.77 ± 0.42 ^a	352.06 ± 1.18 ^a

A (PF) 100% Plantain Flour, **B (SBPF1)** 20% SB +80%PF, **C (SBPF2)** 30% SB +70%PF **D (SBPF3)** 50% SB +50%PF, **E (SB)** 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). Values are mean ± SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).

Table 2. Mineral composition (mg/100 g)

Sample	Ca	Mg	K	Na	Fe	Zn	P
A (PF)	18.42 ± 0.31 ^a	32.18 ± 0.42 ^a	428.35 ± 3.21 ^a	8.26 ± 0.18 ^a	1.84 ± 0.07 ^a	0.72 ± 0.03 ^a	76.24 ± 1.18 ^a
B (SBPF1)	24.67 ± 0.42 ^b	39.54 ± 0.38 ^b	451.62 ± 2.84 ^b	9.13 ± 0.21 ^{ab}	2.31 ± 0.05 ^b	0.91 ± 0.04 ^b	91.36 ± 1.24 ^b
C (SBPF2)	28.53 ± 0.36 ^c	43.82 ± 0.51 ^c	463.47 ± 3.16 ^c	9.76 ± 0.16 ^b	2.67 ± 0.06 ^c	1.04 ± 0.03 ^c	99.42 ± 1.31 ^c
D (SBPF3)	36.84 ± 0.47 ^d	51.63 ± 0.44 ^d	481.29 ± 3.52 ^d	10.82 ± 0.24 ^c	3.21 ± 0.08 ^d	1.27 ± 0.05 ^d	114.68 ± 1.47 ^d
E (SB)	47.26 ± 0.53 ^c	63.74 ± 0.57 ^c	502.83 ± 3.74 ^c	12.46 ± 0.27 ^d	4.08 ± 0.09 ^c	1.56 ± 0.06 ^c	132.47 ± 1.52 ^c

A (PF) 100% Plantain Flour, **B (SBPF1)** 20% SB +80%PF, **C (SBPF2)** 30% SB +70%PF **D (SBPF3)** 50% SB +50%PF, **E (SB)** 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). Values are mean ± SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).

Table 3a. Functional properties

Sample	Bulk density (g/mL)	WAC (%)	OAC (%)	Swelling (%)	Solubility (%)	Dispersibility (%)
A (PF)	0.72 ± 0.01 ^a	142.36 ± 2.14 ^a	108.42 ± 1.86 ^a	6.82 ± 0.18 ^a	7.24 ± 0.21 ^a	72.18 ± 1.25 ^a
B (SBPF1)	0.70 ± 0.01 ^{ab}	151.84 ± 2.36 ^b	113.67 ± 1.92 ^b	7.34 ± 0.16 ^b	7.86 ± 0.18 ^{ab}	75.42 ± 1.18 ^b
C (SBPF2)	0.68 ± 0.01 ^b	158.63 ± 2.18 ^c	117.54 ± 1.74 ^c	7.81 ± 0.21 ^c	8.32 ± 0.24 ^b	77.63 ± 1.34 ^c
D (SBPF3)	0.65 ± 0.01 ^c	169.27 ± 2.47 ^d	123.86 ± 2.05 ^d	8.46 ± 0.19 ^d	9.18 ± 0.22 ^c	80.27 ± 1.16 ^d
E (SB)	0.62 ± 0.01 ^d	181.52 ± 2.63 ^c	131.47 ± 2.17 ^c	9.24 ± 0.23 ^c	10.06 ± 0.26 ^d	83.64 ± 1.29 ^c

A (PF) 100% Plantain Flour, **B** (SBPF1) 20% SB +80%PF, **C** (SBPF2) 30% SB +70%PF **D** (SBPF3) 50% SB +50%PF, **E** (SB) 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).

Table 3b. Foaming and emulsifying properties

Sample	Foaming capacity (%)	Foaming stability (%)	Emulsifying activity (%)	Emulsion stability (%)
A (PF)	8.42 $\pm$ 0.31 ^a	5.36 $\pm$ 0.24 ^a	31.48 $\pm$ 0.72 ^a	27.64 $\pm$ 0.68 ^a
B (SBPF1)	10.76 $\pm$ 0.42 ^b	6.84 $\pm$ 0.31 ^b	35.72 $\pm$ 0.65 ^b	31.28 $\pm$ 0.74 ^b
C (SBPF2)	12.38 $\pm$ 0.36 ^c	8.17 $\pm$ 0.28 ^c	38.64 $\pm$ 0.81 ^c	34.52 $\pm$ 0.63 ^c
D (SBPF3)	14.83 $\pm$ 0.47 ^d	9.86 $\pm$ 0.34 ^d	42.37 $\pm$ 0.76 ^d	38.46 $\pm$ 0.72 ^d
E (SB)	17.26 $\pm$ 0.51 ^e	11.74 $\pm$ 0.39 ^e	46.18 $\pm$ 0.84 ^e	42.73 $\pm$ 0.69 ^e

A (PF) 100% Plantain Flour, **B** (SBPF1) 20% SB +80%PF, **C** (SBPF2) 30% SB +70%PF **D** (SBPF3) 50% SB +50%PF, **E** (SB) 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).

Table 4. Physicochemical properties

Sample	pH	Titrateable acidity (%)	Water activity (aw)	Moisture (%)
A (PF)	6.21 $\pm$ 0.04 ^a	0.18 $\pm$ 0.01 ^a	0.432 $\pm$ 0.006 ^a	7.84 $\pm$ 0.12 ^a
B (SBPF1)	6.14 $\pm$ 0.03 ^{ab}	0.20 $\pm$ 0.01 ^{ab}	0.421 $\pm$ 0.005 ^{ab}	7.67 $\pm$ 0.15 ^a
C (SBPF2)	6.08 $\pm$ 0.04 ^b	0.22 $\pm$ 0.01 ^b	0.413 $\pm$ 0.005 ^b	7.51 $\pm$ 0.10 ^a
D (SBPF3)	5.97 $\pm$ 0.03 ^c	0.25 $\pm$ 0.01 ^c	0.402 $\pm$ 0.004 ^c	7.36 $\pm$ 0.13 ^a
E (SB)	5.86 $\pm$ 0.05 ^d	0.28 $\pm$ 0.02 ^d	0.391 $\pm$ 0.006 ^d	7.18 $\pm$ 0.11 ^a

A (PF) 100% Plantain Flour, **B** (SBPF1) 20% SB +80%PF, **C** (SBPF2) 30% SB +70%PF **D** (SBPF3) 50% SB +50%PF, **E** (SB) 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).

Table 5. Pasting properties

Sample	Peak viscosity (cP)	Trough (cP)	Breakdown (cP)	Final viscosity (cP)	Setback (cP)	Peak time (min)	Pasting temp. (°C)
A (PF)	3184 $\pm$ 42 ^c	1682 $\pm$ 31 ^c	1502 $\pm$ 28 ^c	2968 $\pm$ 37 ^c	1286 $\pm$ 24 ^c	5.12 $\pm$ 0.06 ^a	78.4 $\pm$ 0.4 ^a
B (SBPF1)	2916 $\pm$ 38 ^d	1584 $\pm$ 27 ^d	1332 $\pm$ 24 ^d	2763 $\pm$ 34 ^d	1179 $\pm$ 22 ^d	5.26 $\pm$ 0.05 ^{ab}	79.1 $\pm$ 0.3 ^a
C (SBPF2)	2742 $\pm$ 35 ^c	1518 $\pm$ 29 ^c	1224 $\pm$ 21 ^c	2638 $\pm$ 31 ^c	1120 $\pm$ 19 ^c	5.34 $\pm$ 0.07 ^b	79.7 $\pm$ 0.4 ^{ab}
D (SBPF3)	2418 $\pm$ 41 ^b	1376 $\pm$ 25 ^b	1042 $\pm$ 23 ^b	2394 $\pm$ 29 ^b	1018 $\pm$ 18 ^b	5.48 $\pm$ 0.06 ^c	80.5 $\pm$ 0.3 ^b
E (SB)	2086 $\pm$ 36 ^a	1242 $\pm$ 23 ^a	844 $\pm$ 19 ^a	2158 $\pm$ 27 ^a	916 $\pm$ 17 ^a	5.63 $\pm$ 0.08 ^c	81.3 $\pm$ 0.4 ^c

A (PF) 100% Plantain Flour, **B** (SBPF1) 20% SB +80%PF, **C** (SBPF2) 30% SB +70%PF **D** (SBPF3) 50% SB +50%PF, **E** (SB) 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).

Table 6. Colour characteristics

Sample	L*	a*	b*	Chroma	Hue angle (°)	ΔE
A (PF)	72.64 ± 0.43 ^c	2.18 ± 0.12 ^a	21.73 ± 0.35 ^a	21.84 ± 0.36 ^a	84.26 ± 0.31 ^a	—
B (SBPF1)	68.37 ± 0.51 ^d	2.84 ± 0.14 ^b	20.46 ± 0.41 ^b	20.66 ± 0.42 ^b	82.10 ± 0.38 ^b	4.58 ± 0.27 ^a
C (SBPF2)	65.24 ± 0.46 ^c	3.27 ± 0.13 ^c	19.82 ± 0.37 ^b	20.09 ± 0.38 ^b	80.64 ± 0.35 ^c	7.61 ± 0.32 ^b
D (SBPF3)	60.83 ± 0.54 ^b	3.86 ± 0.16 ^d	18.47 ± 0.43 ^c	18.87 ± 0.44 ^c	78.18 ± 0.42 ^d	12.36 ± 0.41 ^c
E (SB)	56.72 ± 0.48 ^a	4.52 ± 0.18 ^c	17.36 ± 0.39 ^d	17.94 ± 0.41 ^d	75.41 ± 0.46 ^c	17.28 ± 0.48 ^d

A (PF) 100% Plantain Flour, **B** (SBPF1) 20% SB +80%PF, **C** (SBPF2) 30% SB +70%PF **D** (SBPF3) 50% SB +50%PF, **E** (SB) 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). *Values are mean ± SD of triplicate determinations. Means with different superscript letters within the same column are significantly different (p < 0.05).*

Table 7. Anti-nutritional factors

Sample	Phytate (mg/100 g)	Oxalate (mg/100 g)	Tannin (mg/100 g)	Saponin (mg/100 g)	Trypsin inhibitor (TIU/g)	Cyanogenic glycosides (mg HCN/kg)
A (PF)	48.26 ± 1.14 ^a	18.42 ± 0.56 ^a	21.38 ± 0.72 ^a	36.47 ± 0.84 ^a	2.16 ± 0.11 ^a	1.84 ± 0.09 ^a
B (SBPF1)	55.83 ± 1.27 ^b	20.16 ± 0.61 ^{ab}	25.74 ± 0.68 ^b	42.36 ± 0.91 ^b	3.84 ± 0.14 ^b	1.53 ± 0.07 ^b
C (SBPF2)	59.47 ± 1.35 ^c	21.84 ± 0.58 ^b	28.63 ± 0.75 ^c	46.18 ± 1.03 ^c	4.63 ± 0.16 ^c	1.38 ± 0.06 ^b
D (SBPF3)	66.82 ± 1.42 ^d	24.37 ± 0.67 ^c	33.74 ± 0.82 ^d	53.62 ± 1.16 ^d	5.72 ± 0.18 ^d	1.12 ± 0.05 ^c
E (SB)	74.36 ± 1.51 ^e	27.63 ± 0.73 ^d	39.28 ± 0.91 ^e	61.47 ± 1.28 ^e	7.18 ± 0.21 ^e	0.86 ± 0.04 ^d

A (PF) 100% Plantain Flour, **B** (SBPF1) 20% SB +80%PF, **C** (SBPF2) 30% SB +70%PF **D** (SBPF3) 50% SB +50%PF, **E** (SB) 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). *Values are mean ± SD of triplicate determinations. Means with different superscript letters within the same column are significantly different (p < 0.05).*

Table 8. Qualitative phytochemical screening

Phytochemical	A (PF)	B	C	D	E
Alkaloids	+	+	++	++	+++
Flavonoids	+	++	++	+++	+++
Tannins	+	++	++	+++	+++
Saponins	+	++	++	+++	+++
Phenols	+	++	++	+++	+++
Terpenoids	+	+	++	++	++
Steroids	+	+	+	++	++
Glycosides	++	++	++	+++	+++
Anthraquinones	—	—	—	+	+
Phytates	+	++	++	+++	+++

A (PF) 100% Plantain Flour, **B** (SBPF1) 20% SB +80%PF, **C** (SBPF2) 30% SB +70%PF **D** (SBPF3) 50% SB +50%PF, **E** (SB) 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF**

(Sprouted Kidney Bean+ Plantain Flour). *Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).*

Table 9. Quantitative phytochemical composition

Sample	Total phenolics (mg GAE/100 g)	Total flavonoids (mg QE/100 g)	Tannins (mg TAE/100 g)	Saponins (mg/100 g)	Alkaloids (mg/100 g)
A (PF)	82.64 $\pm$ 1.73 ^a	38.27 $\pm$ 1.14 ^a	21.38 $\pm$ 0.72 ^a	36.47 $\pm$ 0.84 ^a	12.63 $\pm$ 0.46 ^a
B (SBPF1)	101.48 $\pm$ 2.16 ^b	47.63 $\pm$ 1.32 ^b	25.74 $\pm$ 0.68 ^b	42.36 $\pm$ 0.91 ^b	15.82 $\pm$ 0.51 ^b
C (SBPF2)	116.73 $\pm$ 2.42 ^c	55.84 $\pm$ 1.47 ^c	28.63 $\pm$ 0.75 ^c	46.18 $\pm$ 1.03 ^c	18.47 $\pm$ 0.58 ^c
D (SBPF3)	139.86 $\pm$ 2.74 ^d	67.52 $\pm$ 1.63 ^d	33.74 $\pm$ 0.82 ^d	53.62 $\pm$ 1.16 ^d	22.64 $\pm$ 0.63 ^d
E (SB)	165.42 $\pm$ 3.08 ^e	81.36 $\pm$ 1.84 ^e	39.28 $\pm$ 0.91 ^e	61.47 $\pm$ 1.28 ^e	27.83 $\pm$ 0.71 ^e

A (PF) 100% Plantain Flour, **B (SBPF1)** 20% SB +80%PF, **C (SBPF2)** 30% SB +70%PF **D (SBPF3)** 50% SB +50%PF, **E (SB)** 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). *Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).*

Table 10. Antioxidant properties

Sample	DPPH inhibition (%)	ABTS inhibition (%)	FRAP (mg TE/100 g)	Total antioxidant capacity (mg AAE/100 g)
A (PF)	24.36 $\pm$ 0.52 ^a	28.47 $\pm$ 0.63 ^a	46.28 $\pm$ 1.17 ^a	58.42 $\pm$ 1.36 ^a
B (SBPF1)	29.84 $\pm$ 0.61 ^b	34.26 $\pm$ 0.58 ^b	55.73 $\pm$ 1.24 ^b	67.35 $\pm$ 1.42 ^b
C (SBPF2)	33.72 $\pm$ 0.47 ^c	39.18 $\pm$ 0.71 ^c	64.82 $\pm$ 1.38 ^c	76.46 $\pm$ 1.58 ^c
D (SBPF3)	41.63 $\pm$ 0.68 ^d	47.54 $\pm$ 0.65 ^d	78.36 $\pm$ 1.52 ^d	91.28 $\pm$ 1.73 ^d
E (SB)	49.27 $\pm$ 0.74 ^e	55.82 $\pm$ 0.79 ^e	93.47 $\pm$ 1.67 ^e	108.64 $\pm$ 1.91 ^e

A (PF) 100% Plantain Flour, **B (SBPF1)** 20% SB +80%PF, **C (SBPF2)** 30% SB +70%PF **D (SBPF3)** 50% SB +50%PF, **E (SB)** 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). *Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).*

Table 11. Glycemic response and GI

Sample	Fasting	15 min	30 min	60 min	90 min	120 min	iAUC	GI
Reference glucose	4.82 $\pm$ 0.11	5.76 $\pm$ 0.14	7.42 $\pm$ 0.18	8.16 $\pm$ 0.21	6.94 $\pm$ 0.17	5.31 $\pm$ 0.13	286.42 $\pm$ 8.31	100.00
A (PF)	4.79 $\pm$ 0.12	5.62 $\pm$ 0.16	7.18 $\pm$ 0.21	7.84 $\pm$ 0.23	6.73 $\pm$ 0.18	5.28 $\pm$ 0.14	273.84 $\pm$ 7.62	95.61
B (SBPF1)	4.81 $\pm$ 0.10	5.48 $\pm$ 0.15	6.91 $\pm$ 0.19	7.42 $\pm$ 0.20	6.42 $\pm$ 0.17	5.22 $\pm$ 0.13	241.67 $\pm$ 6.94	84.36
C (SBPF2)	4.80 $\pm$ 0.11	5.39 $\pm$ 0.14	6.67 $\pm$ 0.18	7.13 $\pm$ 0.19	6.24 $\pm$ 0.16	5.18 $\pm$ 0.12	217.93 $\pm$ 6.47	76.08
D (SBPF3)	4.78 $\pm$ 0.10	5.24 $\pm$ 0.13	6.38 $\pm$ 0.17	6.81 $\pm$ 0.18	6.03 $\pm$ 0.15	5.14 $\pm$ 0.11	188.46 $\pm$ 5.83	65.80
E (SB)	4.77 $\pm$ 0.12	5.16 $\pm$ 0.14	6.21 $\pm$ 0.16	6.48 $\pm$ 0.17	5.84 $\pm$ 0.14	5.09 $\pm$ 0.12	162.74 $\pm$ 5.21	56.82

A (PF) 100% Plantain Flour, **B (SBPF1)** 20% SB +80%PF, **C (SBPF2)** 30% SB +70%PF **D (SBPF3)** 50% SB +50%PF, **E (SB)** 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). *Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).*

Table 11b. Glycemic load

Sample	GI	Available carbohydrate (g/100 g)	Serving size (g)	Available carbohydrate/serving (g)	GL
A (PF)	95.61	79.99	100	79.99	76.47
B (SBPF1)	84.36	75.63	100	75.63	63.81
C (SBPF2)	76.08	73.39	100	73.39	55.84
D (SBPF3)	65.80	68.49	100	68.49	45.08
E (SB)	56.82	60.77	100	60.77	34.52

A (PF) 100% Plantain Flour, **B (SBPF1)** 20% SB +80%PF, **C (SBPF2)** 30% SB +70%PF **D (SBPF3)** 50% SB +50%PF, **E (SB)** 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). *Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).*

Table 12. Sensory evaluation (9-point hedonic scale)

Sample	Appearance	Colour	Aroma	Taste	Texture	Mouthfeel	Overall acceptability
A (PF)	8.12 $\pm$ 0.63 ^a	8.18 $\pm$ 0.59 ^a	7.86 $\pm$ 0.68 ^a	8.04 $\pm$ 0.65 ^a	8.21 $\pm$ 0.57 ^a	8.14 $\pm$ 0.61 ^a	8.12 $\pm$ 0.55 ^a
B (SBPF1)	7.86 $\pm$ 0.71 ^{ab}	7.82 $\pm$ 0.66 ^{ab}	7.74 $\pm$ 0.63 ^a	7.91 $\pm$ 0.62 ^{ab}	7.88 $\pm$ 0.64 ^{ab}	7.93 $\pm$ 0.60 ^{ab}	7.86 $\pm$ 0.58 ^{ab}
C (SBPF2)	7.63 $\pm$ 0.68 ^b	7.54 $\pm$ 0.72 ^b	7.52 $\pm$ 0.67 ^{ab}	7.68 $\pm$ 0.69 ^b	7.65 $\pm$ 0.61 ^b	7.71 $\pm$ 0.64 ^b	7.64 $\pm$ 0.62 ^b
D (SBPF3)	7.34 $\pm$ 0.73 ^c	7.21 $\pm$ 0.76 ^c	7.28 $\pm$ 0.70 ^b	7.42 $\pm$ 0.71 ^c	7.39 $\pm$ 0.69 ^c	7.46 $\pm$ 0.67 ^c	7.38 $\pm$ 0.65 ^c
E (SB)	6.82 $\pm$ 0.81 ^d	6.74 $\pm$ 0.84 ^d	6.91 $\pm$ 0.79 ^c	6.86 $\pm$ 0.82 ^d	6.78 $\pm$ 0.77 ^d	6.83 $\pm$ 0.80 ^d	6.82 $\pm$ 0.74 ^d

A (PF) 100% Plantain Flour, **B (SBPF1)** 20% SB +80%PF, **C (SBPF2)** 30% SB +70%PF **D (SBPF3)** 50% SB +50%PF, **E (SB)** 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). *Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).*

Phytohaemagglutinin (PHA) Activity of the stiff meal Samples

Sample	FORMULATION	PHA (HU/g)
A (PF)	100% Plantain Flour	ND
B (SBPF1)	20% SB +80%PF	4.8 $\pm$ 0.42
C (SBPF2)	30% SB +70%PF	6.7 $\pm$ 0.46
D (SBPF3)	50% SB +50%PF	9.3 $\pm$ 0.68 ^c
E (SB)	100% Sprouted Kidney Bean	14.6 $\pm$ 0.81

Nd- Not Detected

A (PF) 100% Plantain Flour, **B (SBPF1)** 20% SB +80%PF, **C (SBPF2)** 30% SB +70%PF **D (SBPF3)** 50% SB +50%PF, **E (SB)** 100% Sprouted Kidney Bean. **PF** (Plantain Flour), **SB** (Sprouted Kidney Bean), **SBPF** (Sprouted Kidney Bean+ Plantain Flour). *Values are mean $\pm$ SD of triplicate determinations. Means with different superscript letters within the same column are significantly different ($p < 0.05$).*

DISCUSSION

The proximate composition presented in Table 1 demonstrates that incorporation of sprouted kidney bean flour substantially modified the nutritional composition of the unripe plantain-based stiff meal. A progressive increase in protein, fibre and ash was observed with increasing levels of sprouted kidney bean flour, whereas carbohydrate

content generally declined. Protein increased from 5.82% in sample A (100% plantain) to 9.14% in B, 10.68% in C and 14.27% in D, with the highest value of 20.41% recorded in sample E (100% sprouted kidney bean). This represents a substantial improvement in the protein density of the plantain-based product and confirms the complementary nutritional contribution of kidney bean to plantain flour.

The increase in protein can be attributed primarily to the relatively higher protein concentration of kidney bean compared with plantain. Consequently, progressive substitution of plantain flour with kidney bean flour increased the proportion of protein in the composite system. The increase may also have been influenced by sprouting, during which enzymatic activities modify storage proteins and other seed components. Similar changes in the nutritional characteristics of germinated legumes have been reported by Srenuja et al. (2023).

Crude fibre followed a similar pattern, increasing from 2.31% in sample A to 4.16% in D and 5.02% in E. This increase is nutritionally relevant because dietary fibre can contribute to gastrointestinal function, satiety and modulation of postprandial glucose response. The higher fibre content of the kidney bean-containing formulations may therefore contribute, in part, to their improved glycemic characteristics observed subsequently.

Ash content also increased with increasing kidney bean incorporation, indicating greater mineral density in the composite products. In contrast, carbohydrate decreased from 79.99% in sample A to 68.49% in D and 60.77% in E. This reduction is expected because increasing kidney bean flour progressively displaced the carbohydrate-rich plantain flour. The pattern demonstrates the nutritional advantage of composite formulation: the plantain component contributes substantial carbohydrate and energy, while kidney bean provides additional protein, fibre and minerals.

Despite the reduction in carbohydrate, energy values did not decline proportionately. The energy value was 354.86 kcal/100 g in sample A and 352.30 kcal/100 g in sample D, suggesting that the increased contribution of protein and fat partly compensated for the reduction in carbohydrate. Overall, the results indicate that sprouted kidney bean incorporation can improve the nutritional density of plantain-based stiff meal without causing a major reduction in energy content.

The mineral composition in Table 2 indicates that increasing sprouted kidney bean incorporation generally enhanced the mineral content of the products. Calcium increased from 18.42 mg/100 g in sample A to 36.84 mg/100 g in sample D, while magnesium increased from 32.18 to 51.63 mg/100 g over the same substitution range. Potassium remained the most abundant mineral, increasing from 428.35 mg/100 g in A to 481.29 mg/100 g in D. Iron increased from 1.84 to 3.21 mg/100 g, zinc from 0.72 to 1.27 mg/100 g, and phosphorus from 76.24 to 114.68 mg/100 g.

The consistent increase in mineral concentration reflects the contribution of kidney bean to the mineral profile of the composite food. The particularly notable increase in iron and zinc is nutritionally relevant because these minerals play important roles in haemoglobin synthesis, immune function, enzymatic reactions and normal physiological development.

However, the mineral results should be interpreted together with the anti-nutritional-factor data. The presence of phytate and other mineral-binding compounds may reduce the bioavailability of some minerals despite their higher analytical concentrations. Thus, the results demonstrate improvement in mineral content, but not necessarily equivalent improvement in mineral absorption.

The overall increase in mineral concentration nevertheless supports the use of sprouted kidney bean as a nutritional fortificant for unripe plantain-based staple foods.

The functional properties showed marked modification with increasing sprouted kidney bean incorporation. Water absorption capacity, oil absorption capacity, swelling capacity, solubility and dispersibility increased progressively, while bulk density declined. Foaming and emulsifying capacities also improved as the proportion of kidney bean flour increased.

The increase in water absorption may be associated with the higher protein and fibre contents introduced by kidney bean flour. Proteins possess hydrophilic functional groups that can bind water, while dietary fibre can retain water within its matrix. This characteristic is particularly important in stiff-meal production because water absorption influences dough formation, consistency and final eating quality.

The increased oil absorption capacity suggests improved interaction between the composite flour and lipid components. This may be associated with hydrophobic regions of proteins and other flour constituents capable of physically binding oil. Similarly, increased foaming and emulsifying capacities indicate that the additional protein fraction contributed by kidney bean improved the surface-active functionality of the composite flour.

Therefore, the results demonstrate that incorporation of sprouted kidney bean modified not only the nutritional quality but also the technological functionality of the flour. This could broaden the potential applications of the composite flour beyond stiff-meal production.

The physicochemical characteristics demonstrated a gradual shift in acidity with increasing sprouted kidney bean incorporation. The pH decreased from 6.21 in sample A to 5.97 in sample D and 5.86 in sample E, while titratable acidity increased from 0.18% in A to 0.25% in D and 0.28% in E. Water activity similarly declined from 0.432 in A to 0.402 in D and 0.391 in E.

The reduction in pH and corresponding increase in titratable acidity indicate that the incorporation of sprouted kidney bean altered the acid-base characteristics of the flour system. Germination involves considerable metabolic activity, which may alter the concentration and distribution of organic acids and other soluble constituents.

The decline in water activity is potentially advantageous from a storage perspective because microbial growth generally becomes increasingly restricted as water availability decreases. Nevertheless, water activity should be interpreted together with moisture content and storage conditions rather than used alone to predict shelf stability.

The observed physicochemical changes demonstrate that increasing sprouted kidney bean incorporation produced measurable modifications in the chemical environment of the composite flour.

Table 5 demonstrates substantial changes in pasting characteristics as sprouted kidney bean flour replaced plantain flour. Peak viscosity decreased from 3184 cP in sample A to 2418 cP in D and 2086 cP in E. Similar downward trends were observed for trough, breakdown, final and setback viscosities. Conversely, peak time increased from 5.12 min in A to 5.48 min in D and 5.63 min in E, while pasting temperature increased from 78.4°C to 80.5°C and 81.3°C, respectively.

The decline in peak viscosity indicates reduced starch swelling and paste development as the proportion of plantain starch was progressively diluted with kidney bean flour. The protein and fibre components of kidney bean may compete with starch for available water, thereby restricting starch granule swelling during heating.

The lower breakdown viscosity suggests that the composite pastes became more resistant to thermal and mechanical shear during heating. Likewise, reduced setback viscosity may indicate a lower tendency for starch molecules to reassociate during cooling. These characteristics may have implications for the texture and storage stability of the cooked stiff meal.

The increased pasting temperature and peak time further indicate that higher levels of kidney bean flour required greater thermal input and/or longer heating to achieve maximum paste development. Thus, formulation with sprouted kidney bean significantly altered the processing behaviour of the plantain flour.

The colour results showed a clear reduction in lightness with increasing sprouted kidney bean incorporation. L^* decreased from 72.64 in sample A to 60.83 in D and 56.72 in E, indicating progressive darkening of the products. Redness increased, whereas yellowness, chroma and hue angle generally declined.

The darker colour is primarily attributable to the natural pigmentation of kidney bean and the increased contribution of the bean fraction at higher substitution levels. Processing conditions, including drying, sprouting

and cooking, may also contribute to colour development through chemical reactions involving sugars, proteins and phenolic compounds.

Colour is particularly important for a traditional staple because consumers may associate the conventional product with a characteristic appearance. The progressive reduction in lightness therefore provides a plausible explanation for the decline in sensory appearance and colour scores at higher substitution levels.

The result illustrates an important product-development trade-off: increasing kidney bean incorporation improves nutritional characteristics but modifies the visual appearance of the traditional product.

The results presented in Table 7 indicate that phytate, oxalate, tannin, saponin and trypsin inhibitor activity generally increased as sprouted kidney bean incorporation increased, whereas cyanogenic glycosides decreased. Phytate increased from 48.26 mg/100 g in A to 66.82 mg/100 g in D, tannin increased from 21.38 to 33.74 mg/100 g, while trypsin inhibitor activity increased from 2.16 to 5.72 TIU/g. Cyanogenic glycosides, in contrast, declined from 1.84 to 1.12 mg HCN/kg over the same range.

The increase in phytate, tannin and trypsin inhibitor activity is consistent with the greater contribution of kidney bean to the composite flour because these compounds naturally occur in legumes. Although sprouting can reduce certain anti-nutritional factors through enzymatic degradation and metabolic utilization, the extent of reduction varies according to the compound, germination duration and processing conditions.

The increase in phytate is particularly important because phytate can form complexes with minerals and potentially reduce their bioavailability. Consequently, the improved mineral concentrations observed in Table 2 should not be interpreted independently of the anti-nutritional results.

The reduction in cyanogenic glycosides is favourable and may be associated with processing of the plantain component, including drying and cooking. Overall, the findings emphasize that nutritional enrichment should be accompanied by adequate processing to minimize undesirable anti-nutritional compounds.

Qualitative phytochemical screening demonstrated the presence of several bioactive constituents, including alkaloids, flavonoids, tannins, saponins, phenols, terpenoids, steroids, glycosides and phytates. The intensity or detection of several constituents increased with greater kidney bean incorporation. Anthraquinones were detected particularly in the higher kidney bean formulations.

Quantitative analysis further showed that total phenolic content increased from 82.64 mg GAE/100 g in A to 139.86 mg GAE/100 g in D and 165.42 mg GAE/100 g in E. Total flavonoid content similarly increased from 38.27 mg QE/100 g in A to 67.52 mg QE/100 g in D and 81.36 mg QE/100 g in E.

The increase in phenolics and flavonoids demonstrates that kidney bean contributed substantially to the bioactive composition of the composite flour. Germination may further influence these compounds by modifying the plant matrix and promoting the release or transformation of bound phenolic constituents.

The increased concentration of these compounds is potentially beneficial because phenolics and flavonoids are associated with antioxidant activity. However, some phytochemicals, particularly tannins and phytates, can also have anti-nutritional effects. The nutritional interpretation of the phytochemical results should therefore distinguish between potentially beneficial bioactive compounds and compounds that may adversely affect nutrient utilization.

The antioxidant results demonstrated an overall improvement with increasing sprouted kidney bean incorporation. DPPH radical-scavenging activity, ABTS activity, FRAP and total antioxidant capacity increased progressively across the formulations.

This trend corresponds with the progressive increase in total phenolic and flavonoid contents. Phenolic compounds can donate electrons or hydrogen atoms to reactive species, while flavonoids possess structural characteristics that enable them to participate in radical-scavenging reactions. The increased antioxidant activity

may therefore be partly associated with the higher concentration of these compounds in the kidney bean-containing formulations.

The result supports the potential functional-food value of the composite product. Nevertheless, the assays represent in-vitro antioxidant capacity and should not be interpreted as direct evidence that consumption of the product will produce an equivalent antioxidant effect in humans. Bioaccessibility, digestion and metabolism can substantially influence the physiological activity of food-derived antioxidants.

The glycemic-index results in Table 10 demonstrate one of the most significant effects of sprouted kidney bean incorporation. GI decreased progressively from 95.61 in sample A to 84.36 in B, 76.08 in C and 65.80 in D, while sample E recorded the lowest value of 56.82.

The reduction in GI indicates that increasing the proportion of sprouted kidney bean altered the postprandial glucose response of the stiff meal. Several compositional changes observed in the study may contribute to this effect. First, carbohydrate content decreased progressively with increasing kidney bean incorporation. Second, protein and dietary fibre increased. Third, the altered pasting properties indicate that kidney bean components interfered with starch swelling and paste formation.

These changes can collectively reduce the rate at which starch is hydrolysed and glucose becomes available for absorption. The fibre fraction may also delay gastric emptying and reduce the rate of carbohydrate digestion. The presence of resistant starch in unripe plantain may further contribute to the glycemic characteristics of the products.

The reduction from 95.61 in the control to 65.80 in the 50:50 formulation represents a substantial improvement in glycemic response while maintaining a composite product rather than relying exclusively on kidney bean flour. This finding is particularly relevant to the stated objective of developing a traditional staple with more favourable glycemic characteristics.

The glycemic-load values followed the same general pattern as the GI results. GL decreased from 76.47 in A to 63.81 in B, 55.84 in C and 45.08 in D, while E recorded 34.52.

The decline in GL is important because GL considers both the glycemic index and the quantity of available carbohydrate consumed. Therefore, the lower values observed with increasing kidney bean incorporation reflect not only changes in the rate of glucose release but also the reduction in available carbohydrate content of the composite meals.

The progressive reduction in GL strengthens the evidence that incorporation of sprouted kidney bean can modify the carbohydrate quality and quantity of the plantain-based product. Nevertheless, GI and GL are properties of the complete food and serving size; therefore, the results should be interpreted within the specific serving and preparation conditions used in the study.

The PHA results demonstrated a clear formulation-dependent increase. PHA was not detected in sample A, whereas activity increased from 4.8 HU/g in B to 6.7 HU/g in C and 9.3 HU/g in D, reaching 14.6 HU/g in E.

The progressive increase is expected because kidney bean is the principal source of PHA in the formulations. Therefore, increasing kidney bean incorporation inevitably increases the potential contribution of kidney-bean lectins to the final product.

This finding has important food-safety implications. Sprouting and cooking are important processing steps for reducing the activity of heat-sensitive kidney-bean lectins. However, the detection of PHA in the composite formulations emphasizes the need for adequate and validated thermal processing, particularly at high levels of kidney bean incorporation.

Thus, nutritional and glycemic advantages at higher substitution levels must be balanced against food-safety considerations. The 50% formulation should therefore only be recommended after confirming that the adopted processing conditions adequately reduce PHA to an acceptable level.

The sensory results showed that increasing sprouted kidney bean incorporation progressively reduced consumer acceptability. Overall acceptability decreased from 8.12 in sample A to 7.86 in B, 7.64 in C and 7.38 in D, with the lowest score of 6.82 recorded for E.

The decline may be associated with changes in appearance, flavour, aroma and texture resulting from increasing kidney bean incorporation. The colour results provide particularly strong evidence for the effect of formulation on appearance, as L^* decreased markedly with increasing kidney bean content.

Despite the decline, the mean acceptability scores remained above the midpoint of the 9-point hedonic scale. This indicates that the products were generally acceptable to the sensory panel. The 20% formulation was particularly notable because it retained a relatively high acceptability score of **7.86** while providing improvements in nutritional composition and glycemic characteristics.

The results therefore suggest that there is a practical limit to the level of kidney bean substitution that can be used without compromising consumer preference.

When the results from all tables are considered together, a clear formulation-dependent pattern emerges. Increasing sprouted kidney bean incorporation improved protein, fibre, ash, mineral content, phytochemical concentration and antioxidant activity, while reducing carbohydrate content, glycemic index and glycemic load.

However, increasing kidney bean incorporation also produced several undesirable effects, including increased anti-nutritional factors and PHA, reduced pasting viscosities, darker colour and declining sensory acceptability.

The results therefore do not support simply selecting the formulation with the highest kidney bean content. Instead, the most appropriate formulation should be determined by balancing nutritional improvement, glycemic response, processing behaviour, food safety and consumer acceptability.

On this basis, sample D (50% sprouted kidney bean + 50% plantain) appears particularly promising from a nutritional and glycemic perspective because it substantially increased protein and fibre while reducing GI to 65.80 and GL to 45.08. However, its higher PHA and anti-nutritional-factor values and lower sensory scores compared with the lower-substitution formulations must be considered. Conversely, sample B (20% sprouted kidney bean + 80% plantain) offers a stronger compromise where sensory acceptability is prioritized, recording an overall acceptability score of 7.86 while still improving the nutritional and glycemic profile relative to the control.

Therefore, the findings demonstrate that sprouted kidney bean is a promising functional ingredient for nutritional enrichment of unripe plantain stiff meal, but optimization of the incorporation level is essential. The most suitable formulation should be selected according to the intended application—whether the priority is maximum nutritional/glycemic improvement or maximum consumer acceptability—while ensuring adequate processing to control anti-nutritional factors and phytohaemagglutinin.

CONCLUSION

This study demonstrated that the incorporation of sprouted kidney bean flour into unripe plantain flour substantially modified the nutritional, functional, physicochemical, bioactive, glycemic and sensory characteristics of the resulting stiff meal. The progressive incorporation of sprouted kidney bean flour improved the nutritional quality of the plantain-based product, particularly through increases in protein, crude fibre, ash and mineral contents, while producing a corresponding reduction in carbohydrate content. This confirms the complementary nutritional benefits of combining protein-rich legume flour with carbohydrate-dense unripe plantain flour.

The composite formulations also exhibited important functional changes. Increasing sprouted kidney bean incorporation enhanced water absorption, oil absorption, swelling, solubility, dispersibility, foaming and emulsifying properties, although it resulted in reductions in bulk density and pasting viscosities. These changes

indicate that sprouted kidney bean flour can significantly influence the processing behaviour and textural characteristics of plantain-based stiff meal.

The study further established that sprouted kidney bean incorporation increased the phenolic and flavonoid contents and antioxidant activities of the products. However, the increase in kidney bean inclusion was also associated with higher levels of some anti-nutritional factors, particularly phytate, tannin, saponin and trypsin inhibitor activity. Phytohaemagglutinin activity also increased with increasing kidney bean incorporation, emphasizing the importance of adequate sprouting and thermal processing to ensure the safety of kidney bean-containing products.

A particularly important finding was the progressive improvement in the glycemic characteristics of the stiff meals. Glycemic index decreased from 95.61 in the 100% plantain formulation to 65.80 in the 50:50 sprouted kidney bean–plantain formulation, while glycemic load decreased from 76.47 to 45.08. This reduction is associated with the increased protein and fibre contents and the reduced carbohydrate concentration of the composite formulations, as well as changes in starch-related functional properties.

Despite these nutritional and functional improvements, increasing kidney bean incorporation negatively affected some sensory characteristics. Overall acceptability decreased from 8.12 in the control to 7.38 in the 50:50 formulation and 6.82 in the 100% sprouted kidney bean formulation. Nevertheless, the composite products remained generally acceptable to the sensory panel.

Overall, the findings indicate that sprouted kidney bean–unripe plantain flour blends have considerable potential for the development of nutritionally improved stiff meal with more favourable glycemic characteristics. Among the formulations, the 50:50 sprouted kidney bean–plantain blend demonstrated a particularly favourable nutritional and glycemic profile, although its higher phytohaemagglutinin and anti-nutritional-factor levels and comparatively lower sensory acceptability must be considered. The 20:80 formulation provides an alternative where greater consumer acceptability is prioritized. Therefore, the study concludes that appropriate optimization of sprouted kidney bean incorporation, together with adequate processing to control anti-nutritional factors and phytohaemagglutinin, can provide a practical approach to improving the nutritional and functional quality of a culturally important Nigerian staple food.

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