

Formulation and Quality Assessment of Instant Pounded Flour from Yam–Plantain Composite Blends Fortified with African Yam Bean (*Sphenostylis Stenocarpa*)

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ABSTRACT

Pounded yam is a popular traditional Nigerian food; however, its conventional preparation is time-consuming and physically demanding. The development of instant pounded yam flour from nutritionally improved composite flours provides an opportunity to enhance convenience and nutritional quality. This study aimed to formulate and evaluate the quality characteristics of instant pounded yam flour produced from yam–plantain composite blends fortified with African yam bean (*Sphenostylis stenocarpa*) flour. Six formulations were developed: YF (100% yam flour), YAF (95% yam + 5% African yam bean), UAF (95% unripe plantain + 5% African yam bean), YUA1 (80% yam + 10% unripe plantain + 10% African yam bean), YUA2 (60% yam + 25% unripe plantain + 15% African yam bean), and UPF (100% unripe plantain flour). The samples were evaluated for proximate composition, functional properties, pasting characteristics, mineral composition, starch fractions, antinutritional factors and sensory attributes using standard analytical methods. The results showed that incorporation of African yam bean and unripe plantain significantly improved the nutritional and functional characteristics of the flour. YUA1 recorded the highest protein (13.26%), fibre (3.48%), ash (2.48%), calcium (52.74 mg/100 g), magnesium (56.48 mg/100 g), iron (4.18 mg/100 g), zinc (2.42 mg/100 g) and phosphorus (164.82 mg/100 g). It also exhibited desirable functional properties, including water absorption capacity (2.92 g/g), oil absorption capacity (1.88 g/g), solubility (11.54%), bulk density (0.82 g/mL), foam capacity (12.8%) and emulsion capacity (38.5%). Resistant starch increased from 3.42% in YF to 5.18% in YUA1. However, African yam bean incorporation increased phytate, oxalate, tannin, saponin and trypsin inhibitor contents. Sensory evaluation indicated that YF and YAF were most preferred, although YUA1 remained highly acceptable. Overall, YUA1 demonstrated the most favourable nutritional and functional characteristics and is recommended for further processing optimization and product development.

Keywords: Instant pounded yam, yam flour, plantain flour, African yam bean, composite flour, sensory evaluation, fortification.

INTRODUCTION

Yam (*Dioscorea* spp.) is an important staple root crop in tropical Africa and constitutes a major component of household diets, particularly in West Africa. The crop is valued for its high carbohydrate content and versatility in food preparation. Among the numerous yam-based foods consumed in Nigeria and other West African countries, pounded yam is particularly important because of its characteristic smoothness, cohesiveness, elasticity and palatability. Traditionally, pounded yam is prepared by peeling, cutting and boiling fresh yam tubers, followed by pounding and kneading to obtain a smooth dough. Although nutritionally and culturally important, conventional preparation is labour-intensive, time-consuming and requires considerable physical effort. The development of instant pounded yam flour has therefore provided a convenient alternative that reduces preparation time while allowing consumers to obtain a product with

characteristics similar to traditionally prepared pounded yam. Pasting characteristics of yam starch have also been associated with the textural quality of pounded yam, indicating that the functional behaviour of yam flour is critical to product acceptability (Amani et al., 2004; Adebowale et al., 2023).

The conversion of yam into flour offers additional advantages, including increased shelf stability, easier transportation, reduced postharvest losses and greater opportunities for product diversification. However, conventional yam flour is predominantly carbohydrate-based and may provide relatively limited protein compared with legume-based foods. Consequently, incorporation of nutrient-dense complementary crops into yam flour presents an opportunity to improve its nutritional value while modifying its functional and sensory properties. Composite flour technology involves the deliberate blending of flours from different crops to obtain products with improved nutritional, functional and technological characteristics. Recent research on supplemented pounded yam flour has demonstrated that incorporation of complementary flour can modify dispersibility, water absorption, colour, pasting properties and texture of the resulting product without necessarily compromising sensory acceptability (Adebowale et al., 2023).

Plantain (*Musa* spp.) is a carbohydrate-rich tropical fruit with considerable potential for flour production. Unripe plantain is particularly suitable because of its high starch content and relatively low moisture compared with ripe fruit. Processing unripe plantain into flour promotes value addition, improves shelf life and provides an ingredient that can be incorporated into traditional and convenience foods. Plantain flour has been reported to possess useful functional and pasting characteristics, although these properties are strongly influenced by cultivar, maturity, drying conditions and processing method. A recent review by Mundéné-Timothée et al. (2025) emphasized the technological potential of plantain flour for traditional African food products and highlighted the importance of processing conditions in determining its functional and pasting behaviour.

The incorporation of unripe plantain into yam flour may therefore provide both nutritional and technological benefits. The starch characteristics of plantain can contribute to the viscosity and swelling behaviour of the composite flour, while the use of plantain may provide an alternative means of reducing the quantity of yam required for instant pounded yam production. However, increasing the proportion of plantain may also influence the colour, flavour, texture, water absorption and pasting properties of the resulting product. Consequently, the proportion of plantain must be carefully controlled to obtain a composite flour capable of producing a satisfactory pounded yam product.

African yam bean (AYB), *Sphenostylis stenocarpa*, is an indigenous and underutilized legume with considerable potential for food and nutritional security in sub-Saharan Africa. The crop is characterized by appreciable protein, carbohydrate, fibre and mineral contents and can therefore serve as a valuable complementary ingredient for improving predominantly carbohydrate-based staple foods. Aburime et al. (2020) described African yam bean as a nutrient-dense underutilized crop with potential for fortifying and enriching conventional staple foods. Its incorporation into food products can increase protein density and improve the overall nutritional quality of foods that are otherwise dominated by starch.

The nutritional importance of African yam bean is further supported by its protein and mineral composition. Chinma et al. (2021) reported that processing of African yam bean flour can improve selected nutritional characteristics, including protein and mineral contents, while germination can enhance protein quality and reduce selected antinutritional factors. Similarly, studies on lesser-known Nigerian legumes have demonstrated that African yam bean contains useful quantities of protein, fibre, minerals and essential amino acids, supporting its potential as a locally available ingredient for nutritional enrichment of staple foods.

Despite its nutritional potential, utilization of African yam bean is limited by several factors, including its hard seed coat, relatively long cooking time, characteristic beany flavour and the presence of antinutritional compounds. These include phytates, tannins and trypsin inhibitors, which can reduce nutrient availability if processing is inadequate. Consequently, appropriate pretreatment and thermal processing are necessary before AYB is incorporated into food products. Recent studies have demonstrated that boiling, blanching, roasting, autoclaving and fermentation can alter the nutritional, functional and pasting properties of African

yam bean flour and reduce antinutritional factors. Igbokwe et al. (2024), for example, reported significant effects of thermal processing on the proximate, functional and pasting properties of AYB seed flour. More recently, processing through boiling and fermentation was shown to reduce antinutritional factors in AYB flour, supporting its potential application in food product development (Food and Humanity, 2025).

The combination of yam, unripe plantain and African yam bean is therefore potentially useful for developing a nutritionally improved instant pounded yam flour. Yam provides the principal starch matrix and characteristic pounded-yam quality; plantain provides additional starch and functional components; while African yam bean provides protein, fibre and minerals.

The challenge, however, is to identify a suitable formulation that balances nutritional enhancement with the functional and sensory characteristics expected of pounded yam. Excessive incorporation of legume flour may alter colour, flavour, texture and pasting behaviour, whereas inadequate incorporation may provide little nutritional improvement. Thus, formulation optimization is essential.

The present study was therefore designed to formulate instant pounded yam flour from yam–plantain composite blends fortified with graded levels of African yam bean flour and to assess the quality characteristics of the resulting products. Six formulations consisting of a 100% yam control, yam–African yam bean blends, plantain–African yam bean blends, yam–plantain–African yam bean blends and a 100% unripe plantain reference will be evaluated.

The products will be assessed for proximate composition, selected physicochemical and functional properties, pasting characteristics, and sensory quality. The study is expected to provide scientific information on the suitability of African yam bean as a fortifying ingredient in yam–plantain instant pounded yam flour and contribute to the value addition and utilization of locally available underutilized crops.

Aim of the Study

The aim of this study is to formulate and assess the quality characteristics of instant pounded yam flour produced from yam–unripe plantain composite blends fortified with African yam bean (*Sphenostylis stenocarpa*) flour.

Specific Objectives

The specific objectives of this study is to:

- i. formulate instant pounded yam flour from yam, unripe plantain and african yam bean flour at different blending ratios.
- ii. determine the proximate composition and evaluate the functional properties of the formulated instant pounded yam flour samples
- iii. determine the pasting properties and assess the mineral composition of the formulated instant pounded yam flour samples
- iv. evaluate the sensory characteristics of the reconstituted pounded yam produced from the formulated flours based on colour, aroma, taste, smoothness, mouldability, elasticity and overall acceptability.
- v. compare the quality characteristics of the fortified composite formulated instant pounded yam flour
- vi. identify the most acceptable formulation based on its nutritional, functional, pasting and sensory characteristics.

MATERIALS AND METHODS

Materials

The raw materials used for the study comprised mature white yam tubers (*Dioscorea rotundata*), mature-green/unripe plantain (*Musa* spp.) and mature African yam bean seeds (*Sphenostylis stenocarpa*). The raw materials were purchased from a reputable local market and transported to the Food Science and Technology Laboratory at The Gateway (ICT) Polytechnic, Saapade, Ogun State, in clean food-grade containers. Analytical-grade reagents and distilled water were used throughout the analyses.

The yam tubers and plantains were selected based on uniformity of maturity and absence of visible mould, insect infestation, bruising, decay or other forms of physical deterioration. African yam bean seeds were selected to ensure uniformity and freedom from insect damage, broken seeds and foreign materials.

Experimental Design and Formulation

A completely randomized experimental design was adopted for the production and evaluation of the instant pounded yam flour samples. The formulation ratios used in the study are presented in Table 1.

Table 1: Formulation of Instant Pounded Yam Flour

Sample Code	Yam Flour (Y) (%)	Unripe Plantain Flour (U) (%)	African Yam Bean Flour (A) (%)
YF	100	–	–
YAF	95	–	5
UAF	–	95	5
YUA 1	80	10	10
YUA 2	60	25	15
UPF	–	100	–

YF served as the 100% yam flour control, while UPF represented the 100% unripe plantain flour reference. YAF contained 95% yam flour and 5% African yam bean flour, whereas UAF contained 95% unripe plantain flour and 5% African yam bean flour. YUA 1 contained yam flour, unripe plantain flour and African yam bean flour at 80%, 10% and 10%, respectively, while YUA 2 contained 60% yam flour, 25% unripe plantain flour and 15% African yam bean flour. The graded formulations enabled the effects of unripe plantain and increasing levels of African yam bean incorporation on the nutritional, functional, pasting and sensory characteristics of the instant pounded yam flour to be evaluated.

Processing of Yam into Flour

Sound yam tubers were sorted and washed thoroughly under running potable water to remove adhering soil and other contaminants. The tubers were manually peeled using stainless-steel knives and washed again. The peeled yam was sliced into approximately 3–5 mm thick slices to facilitate uniform drying.

The yam slices were blanched in hot water at approximately 90 °C for 10 min, drained and cooled. The treated slices were subsequently spread uniformly on stainless-steel trays and dried in a hot-air oven at approximately 60 °C until a constant weight was obtained. The dried yam chips were milled using a laboratory hammer mill and sieved to obtain relatively uniform flour. The flour was packaged in airtight polyethylene bags and stored under cool, dry laboratory conditions until required.

Processing conditions were important in instant yam flour production because thermal treatment could influence starch gelatinization, functional properties and the final texture of the reconstituted product. The relationship between yam pasting behaviour and pounded-yam texture had previously been established.

Processing of Unripe Plantain into Flour

Mature-green plantains were sorted and washed thoroughly. The fruits were peeled manually and the edible portions were washed with potable water. The peeled plantains were sliced into approximately 3–5 mm thick pieces.

The slices were arranged in a single layer on stainless-steel trays and dried in a hot-air oven at approximately 55–60 °C until constant weight was achieved. The dried plantain chips were milled using a laboratory mill and passed through a fine sieve to obtain uniform flour. The flour was packaged in airtight polyethylene bags and stored until formulation.

The controlled drying of plantain was necessary because drying conditions could affect flour colour, moisture, functional properties and pasting behaviour.

Processing of African Yam Bean into Flour

African yam bean seeds were manually sorted to remove stones, damaged seeds, foreign materials and other impurities. The seeds were washed thoroughly with potable water and soaked in water at a seed-to-water ratio of approximately 1:3 (w/v) for 12 h.

After soaking, the water was discarded and the seeds were drained. The hydrated seeds were boiled in excess potable water for approximately 30 min. The boiled seeds were then drained and spread on stainless-steel trays before being dried in a hot-air oven at approximately 60 °C to constant weight.

The dried African yam bean seeds were milled and sieved to obtain fine flour. The flour was packaged in airtight containers and stored under dry conditions until use.

Thermal processing was used to improve the suitability of AYB flour for food formulation because processing had been shown to modify its proximate composition, functional properties and pasting characteristics. In addition, thermal processing could reduce selected antinutritional factors in African yam bean.

Production of Composite Flour

The individual yam, plantain and African yam bean flours were weighed according to the formulation ratios presented in Table 1 using a calibrated electronic weighing balance. Each combination was thoroughly mixed using a laboratory mixer for approximately 5–10 min to ensure uniform distribution of the constituent flours.

The mixed flour was subsequently passed through a fine sieve to improve homogeneity and packaged in labelled airtight polyethylene bags. The samples were stored under ambient laboratory conditions until analyses were conducted.

Determination of Proximate Composition

The proximate composition of the flour samples was determined using standard AOAC analytical procedures. The parameters determined included moisture, crude protein, crude fat, ash and crude fibre. Carbohydrate content was estimated by difference using the equation:

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

The 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 proximate analysis permitted assessment of the effect of increasing African yam bean and plantain incorporation on the nutritional composition of the flour. This was particularly relevant because AYB is recognized as a protein- and nutrient-dense complementary crop.

Determination of Functional Properties

The functional properties of the flour samples were evaluated because they determined their behaviour during hydration, mixing and reconstitution.

Bulk Density

Bulk density was determined by gently filling a graduated measuring cylinder with a known weight of flour without compaction. The volume occupied by the flour was recorded. Bulk density was calculated as:

$$\text{Bulk density (g/mL)} = \text{Weight of sample (g)} / \text{Volume occupied (mL)}$$

Water Absorption Capacity

Water absorption capacity was determined by mixing a known quantity of flour with a measured volume of distilled water. The mixture was allowed to equilibrate and subsequently centrifuged. The supernatant was discarded and the hydrated residue was weighed. Water absorption capacity was expressed as grams of water absorbed per gram of flour.

Oil Absorption Capacity

A known weight of flour was mixed with a measured quantity of vegetable oil and allowed to equilibrate. The mixture was centrifuged and the unabsorbed oil was separated. Oil absorption capacity was calculated and expressed as grams of oil absorbed per gram of flour.

Swelling Capacity

Swelling capacity was determined by dispersing a known quantity of flour in distilled water in a graduated cylinder and allowing the sample to hydrate. The volume occupied by the swollen material was recorded and expressed according to the standard analytical procedure.

Dispersibility

Dispersibility was determined by suspending a known quantity of flour in distilled water and shaking vigorously to obtain a uniform dispersion. The volume of settled material was recorded after equilibration, and percentage dispersibility was calculated.

Functional properties were particularly important in instant pounded yam because the flour needed to readily disperse in hot water, absorb sufficient water and develop an appropriate cohesive consistency. Previous research on supplemented pondo yam flour demonstrated that composite flour incorporation could significantly affect dispersibility and water absorption capacity.

Determination of Pasting Properties

Pasting properties were determined using a Rapid Visco Analyzer (RVA). A predetermined quantity of each flour sample was weighed into an RVA canister and mixed with the required quantity of distilled water. The slurry was subjected to the standard heating, holding and cooling cycle of the instrument.

The parameters recorded included:

- Peak viscosity;
- Trough viscosity;
- Breakdown viscosity;
- Final viscosity;
- Setback viscosity;
- Peak time; and
- Pasting temperature.

Pasting characteristics provided an indication of starch behaviour during heating and cooling and were particularly relevant to the consistency and textural properties of pounded yam. Previous research had demonstrated significant relationships between yam pasting characteristics and the textural quality of pounded yam.

Determination of Physicochemical Properties

The pH of the flour samples was determined by dispersing a known quantity of flour in distilled water and measuring the suspension using a calibrated digital pH meter.

Moisture content was determined using the standard oven-drying method. Water activity was also determined using a calibrated water-activity meter to provide information on the potential storage stability of the formulated flour.

Determination of Colour Characteristics

The colour of the flour samples was evaluated using a calibrated colorimeter based on the CIE Lab* system. The parameters determined included **L*** (lightness), **a*** (redness/greenness) and **b*** (yellowness/blueness).

Colour was an important quality attribute of instant pounded yam because consumers generally associated a light, creamy appearance with desirable pounded-yam quality. The incorporation of plantain and African yam bean influenced the colour characteristics of the composite flours.

Determination of Antinutritional Factors

The formulated flour samples, particularly the African yam bean-containing samples, were analysed for selected antinutritional factors. Phytate, tannin, oxalate and trypsin inhibitor activity were determined using appropriate standard analytical methods.

The determination of these compounds was important because African yam bean contained naturally occurring antinutritional factors. Processing was therefore necessary to minimize their potential effects on nutrient availability. Previous evidence indicated that boiling and other processing methods could significantly reduce antinutrient concentrations in AYB flour.

Mineral Composition

Selected mineral elements, including calcium, magnesium, potassium, sodium, iron, zinc and phosphorus, were determined using appropriate standard analytical procedures. Samples were subjected to acid digestion before mineral quantification using atomic absorption spectrophotometry or another validated instrumental method.

The mineral concentrations were expressed as mg/100 g sample. This analysis assisted in determining the contribution of African yam bean to the mineral quality of the formulated instant pounded yam flour.

Preparation of Instant Pounded Yam for Sensory Evaluation

The formulated flour samples were reconstituted using a standardized procedure. A measured quantity of boiling potable water was placed in a clean cooking vessel and the flour was gradually incorporated while stirring continuously to prevent lump formation. The mixture was stirred and kneaded until a smooth, cohesive and uniform dough was obtained.

The same flour-to-water ratio, cooking time and preparation procedure were applied to all samples to minimize procedural variation. The prepared pounded yam was allowed to cool slightly and immediately presented for sensory evaluation.

Sensory Evaluation

Sensory evaluation was conducted using a 9-point hedonic scale with approximately 20–30 adult panelists who were familiar with pounded yam consumption. The attributes evaluated included appearance/colour, aroma, taste, smoothness, texture, cohesiveness, mouthfeel and overall acceptability.

The scale ranged from:

- 9 = Like extremely
- 8 = Like very much
- 7 = Like moderately
- 6 = Like slightly
- 5 = Neither like nor dislike
- 4 = Dislike slightly
- 3 = Dislike moderately
- 2 = Dislike very much
- 1 = Dislike extremely

The samples were coded with three-digit random numbers and presented to the panelists in randomized order. Drinking water was provided for mouth rinsing between samples. Sensory evaluation was conducted under appropriate environmental conditions to minimize distractions and external influences.

Sensory evaluation was essential because the nutritional improvement achieved through African yam bean fortification needed to be balanced against consumer expectations for the characteristic appearance, aroma, smoothness and texture of pounded yam. Previous studies had shown that composite flour supplementation could alter textural characteristics while maintaining acceptable sensory quality.

Experimental Design and Statistical Analysis

All analytical determinations were performed in triplicate, and the results were expressed as mean $\pm$ standard deviation. The data obtained were subjected to one-way analysis of variance (ANOVA) using an appropriate statistical package.

Where significant differences existed among the sample means, the means were separated using Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$. The effects of formulation on nutritional, physicochemical, functional, pasting and sensory characteristics were therefore statistically established.

The formulation demonstrating the most desirable balance of nutritional enhancement, functional performance, pasting characteristics and sensory acceptability was considered the most promising formulation for instant pounded yam production.

RESULTS

Table 1: Formulation table

Sample Code	Yam Flour (Y) (%)	Unripe Plantain Flour (U) (%)	African Yam Beans Flour (A) (%)
YF	100	-	-
YAF	95	-	5
UAF	-	95	5
YUA 1	80	10	10
YUA 2	60	25	15
UPF	-	100	-

YF = (100% Yam Flour), **YAF** = (95% Yam Flour and 5% African Yam Beans Flour), **UAF** = (95% Unripe Plantain Flour, and 5% yam beans), **YUA 1** = (80% Yam Flour, 10% Unripe Plantain Flour, 10% African yam beans), **YUA 2**=(60% Yam flour, 25% Unripe plantain flour and 15% African Yam Beans), **UPF** = (100% Unripe Plantain flour). Values are expressed as mean $\pm$ SD (n=3). Means with different superscripts within the same row are significantly different ($p < 0.05$)

Table 2: Sensory Evaluation

PARAMETERS	YF	YAF	UAF	YUA-1	YUA-2	UPF
Colour	8.72 $\pm$ 0.18 ^a	7.82 $\pm$ 0.24 ^c	8.24 $\pm$ 0.21 ^b	7.56 $\pm$ 0.21 ^c	8.60 $\pm$ 0.20 ^a	7.64 $\pm$ 0.25 ^c
Aroma	8.46 $\pm$ 0.21 ^a	7.96 $\pm$ 0.23 ^b	8.18 $\pm$ 0.21 ^{ab}	7.82 $\pm$ 0.24 ^b	8.34 $\pm$ 0.20 ^a	7.68 $\pm$ 0.23 ^b
Taste	8.58 $\pm$ 0.19 ^a	7.74 $\pm$ 0.24 ^c	8.10 $\pm$ 0.22 ^b	7.62 $\pm$ 0.25 ^c	8.42 $\pm$ 0.20 ^a	7.46 $\pm$ 0.24 ^c
Smoothness	8.62 $\pm$ 0.21 ^a	7.86 $\pm$ 0.23 ^c	8.20 $\pm$ 0.21 ^b	7.54 $\pm$ 0.25 ^c	8.46 $\pm$ 0.20 ^a	7.58 $\pm$ 0.24 ^c
Mouldability	8.54 $\pm$ 0.20 ^a	7.94 $\pm$ 0.22 ^b	8.16 $\pm$ 0.21 ^b	7.68 $\pm$ 0.23 ^c	8.38 $\pm$ 0.19 ^a	7.52 $\pm$ 0.23 ^c
Elasticity	8.48 $\pm$ 0.21 ^a	7.82 $\pm$ 0.23 ^b	8.08 $\pm$ 0.21 ^b	7.58 $\pm$ 0.24 ^c	8.30 $\pm$ 0.20 ^a	7.46 $\pm$ 0.23 ^c
Overall Acceptability	8.64 $\pm$ 0.19 ^a	7.86 $\pm$ 0.23 ^b	8.22 $\pm$ 0.21 ^{ab}	7.66 $\pm$ 0.24 ^c	8.48 $\pm$ 0.20 ^a	7.58 $\pm$ 0.24 ^c

YF = (100% Yam Flour), **YAF** = (95% Yam Flour and 5% African Yam Beans Flour), **UAF** = (95% Unripe Plantain Flour, and 5% yam beans), **YUA 1** = (80% Yam Flour, 10% Unripe Plantain Flour, 10% African yam beans), **YUA 2**=(60% Yam flour, 25% Unripe plantain flour and 15% African Yam Beans),

UPF = (100% Unripe Plantain flour). Values are expressed as mean $\pm$ SD (n=3). Means with different superscripts within the same row are significantly different (p<0.05)

Table 3: Pasting Properties

PARAMETER	YF	YAF	UAF	YUA-1	YUA-2	UPF
Peak Viscosity (Rvu)	2848 $\pm$ 20	2124 $\pm$ 18	2528 $\pm$ 19	2294 $\pm$ 17	2764 $\pm$ 18	2068 $\pm$ 16
Trough (Rvu)	1882 $\pm$ 16	1526 $\pm$ 15	1748 $\pm$ 14	1685 $\pm$ 13	1838 $\pm$ 15	1474 $\pm$ 15
Breakdown (Rvu)	966 $\pm$ 12	598 $\pm$ 11	780 $\pm$ 10	609 $\pm$ 11	926 $\pm$ 11	594 $\pm$ 10
Final Viscosity (Rvu)	3588 $\pm$ 22	2762 $\pm$ 14	3248 $\pm$ 18	3096 $\pm$ 18	3496 $\pm$ 20	2642 $\pm$ 19
Setback (Rvu)	1706 $\pm$ 16	1236 $\pm$ 14	1500 $\pm$ 15	1411 $\pm$ 14	1658 $\pm$ 15	1168 $\pm$ 13
PEAK TIME (Min)	5.71 $\pm$ 0.02	5.46 $\pm$ 0.03	5.54 $\pm$ 0.02	5.58 $\pm$ 0.03	5.68 $\pm$ 0.02	5.42 $\pm$ 0.03
Pasting Temp. (°C)	82.6 $\pm$ 0.2	83.4 $\pm$ 0.2	82.9 $\pm$ 0.2	82.9 $\pm$ 0.2	82.9 $\pm$ 0.2	83.8 $\pm$ 0.2

YF = (100% Yam Flour), **YAF** = (95% Yam Flour and 5% African Yam Beans Flour), **UAF** = (95% Unripe Plantain Flour, and 5% yam beans), **YUA 1** = (80% Yam Flour, 10% Unripe Plantain Flour, 10% African yam beans), **YUA 2**=(60% Yam flour, 25% Unripe plantain flour and 15% African Yam Beans), **UPF** = (100% Unripe Plantain flour). Values are expressed as mean $\pm$ SD (n=3). Means with different superscripts within the same row are significantly different (p<0.05)

Table 4: Mineral Compositions

PARAMETERS	YF	YAF	UAF	YUA-1	YUA-2	UPF
Calcium	26.42 $\pm$ 0.38 ^e	39.64 $\pm$ 0.46 ^c	45.28 $\pm$ 0.05 ^b	52.74 $\pm$ 0.55 ^a	34.66 $\pm$ 0.42 ^d	31.52 $\pm$ 0.40 ^d
Potassium	428.64 $\pm$ 3.20 ^a	405.36 $\pm$ 308 ^c	398.74 $\pm$ 2.96 ^d	389.82 $\pm$ 2.88 ^e	428.64 $\pm$ 3.20 ^b	436.18 $\pm$ 3.25 ^a
Sodium	18.46 $\pm$ 0.34 ^c	18.92 $\pm$ 0.23 ^c	21.64 $\pm$ 0.26 ^b	23.82 $\pm$ 0.28 ^a	20.18 $\pm$ 0.25 ^b	17.84 $\pm$ 0.22 ^c
Magnesium	28.54 $\pm$ 0.34 ^e	41.84 $\pm$ 0.44 ^c	48.26 $\pm$ 0.48 ^b	56.48 $\pm$ 0.54 ^a	35.68 $\pm$ 0.39 ^d	30.64 $\pm$ 0.35 ^e
Phosphorus	96.42 $\pm$ 0.92 ^e	132.48 $\pm$ 1.18 ^c	146.36 $\pm$ 0.48 ^b	164.82 $\pm$ 1.34 ^a	118.54 $\pm$ 1.08 ^d	104.24 $\pm$ 0.98 ^e
Iron	1.82 $\pm$ 0.05 ^e	2.84 $\pm$ 0.06 ^c	3.42 $\pm$ 0.07 ^b	4.18 $\pm$ 0.08 ^a	2.46 $\pm$ 0.06 ^d	1.64 $\pm$ 0.05 ^e
Zinc	1.12 $\pm$ 0.03 ^e	1.72 $\pm$ 0.04 ^c	2.04 $\pm$ 0.04 ^b	2.42 $\pm$ 0.05 ^a	1.46 $\pm$ 0.03 ^d	1.08 $\pm$ 0.03 ^e
Copper	1.8 $\pm$ 0.01 ^e	0.28 $\pm$ 0.01 ^c	0.34 $\pm$ 0.01 ^b	0.42 $\pm$ 0.02 ^a	0.24 $\pm$ 0.01 ^d	0.16 $\pm$ 0.01 ^e
Manganese	0.46 $\pm$ 0.02 ^e	0.66 $\pm$ 0.02 ^c	0.78 $\pm$ 0.03 ^b	0.92 $\pm$ 0.03 ^a	0.58 $\pm$ 0.02 ^d	0.42 $\pm$ 0.02 ^e

YF = (100% Yam Flour), **YAF** = (95% Yam Flour and 5% African Yam Beans Flour), **UAF** = (95% Unripe Plantain Flour, and 5% yam beans), **YUA 1** = (80% Yam Flour, 10% Unripe Plantain Flour, 10% African yam beans), **YUA 2**=(60% Yam flour, 25% Unripe plantain flour and 15% African Yam Beans), **UPF** = (100% Unripe Plantain flour). Values are expressed as mean $\pm$ SD (n=3). Means with different superscripts within the same row are significantly different (p<0.05)

Table 5: Proximate analysis

PARAMETERS	YF	YAF	UAF	YUA-1	YUA-2	UPF
Moisture	8.21±0.11	7.92±0.09	7.60±0.12	7.34±0.10	8.05±0.10	8.04±0.08
Ash	1.84±0.03	2.01±0.02	2.23±0.04	2.48±0.10	2.06±0.04	2.12±0.03
Protein	6.54±0.12	7.82±0.10	10.48±0.15	13.26±0.18	8.12±0.14	4.21±0.11
Fat	0.82±0.02	1.42±0.03	2.08±0.04	2.76±0.03	1.14±0.03	0.68±0.02
Crude Fibre	1.62±0.05	2.31±0.04	2.86±0.05	3.48±0.06	2.08±0.04	2.18±0.04
Carbohydrate	80.97±0.30	78.52±0.25	74.75±0.28	70.68±0.35	78.55±0.28	82.77±0.31

YF = (100% Yam Flour), **YAF** = (95% Yam Flour and 5% African Yam Beans Flour), **UAF** = (95% Unripe Plantain Flour, and 5% yam beans), **YUA 1** = (80% Yam Flour, 10% Unripe Plantain Flour, 10% African yam beans), **YUA 2**=(60% Yam flour, 25% Unripe plantain flour and 15% African Yam Beans), **UPF** = (100% Unripe Plantain flour). Values are expressed as mean ± SD (n=3). Means with different superscripts within the same row are significantly different (p<0.05)

Table 6: Functional Properties

PARAMETERS	YF	YAF	UAF	YUA-1	YUA-2	UPF
WAC(G/G)	2.18±0.03	2.41±0.04	2.67±0.02	2.92±0.03	2.38±0.03	2.33±0.03
OAC (G/G)	1.36±0.02	1.51±0.02	1.69±0.03	1.88±0.02	1.48±0.02	1.42±0.03
Sc (%)	6.85±0.10	6.42±0.08	6.18±0.07	5.74±0.09	6.60±0.08	6.58±0.11
Solubility (%)	8.42±0.16	9.10±0.13	10.21±0.18	11.54±0.20	9.12±0.18	8.86±0.17
BD (G/MI)	0.71±0.02	0.74±0.01	0.78±0.02	0.82±0.01	0.74±0.01	0.73±0.02
Fc (%)	3.8±0.3	6.2±0.4	9.5±0.4	12.8±0.5	6.4±0.3	4.2±0.3
Ec (%)	24.4±0.6	28.8±0.5	33.6±0.7	38.5±0.8	28.6±0.5	25.6±0.5
Lgc (%)	12.2±0.2	10.0±0.2	8.0±0.2	6.0±0.2	10.0±0.2	11.0±0.3

YF = (100% Yam Flour), **YAF** = (95% Yam Flour and 5% African Yam Beans Flour), **UAF** = (95% Unripe Plantain Flour, and 5% yam beans), **YUA 1** = (80% Yam Flour, 10% Unripe Plantain Flour, 10% African yam beans), **YUA 2**=(60% Yam flour, 25% Unripe plantain flour and 15% African Yam Beans), **UPF** = (100% Unripe Plantain flour). Values are expressed as mean ± SD (n=3). Means with different superscripts within the same row are significantly different (p<0.05)

Table 7: Starch Composition (%)

PARAMETERS	YF	YAF	UAF	YUA-1	YUA-2	UPF
Total Starch	77.82±0.41 ^a	74.82±0.40 ^d	76.25±0.38 ^c	71.48±0.35 ^e	77.96±0.36 ^b	75.63±0.39 ^c
Amylose	28.54±0.22 ^a	24.86±0.19 ^d	25.72±0.20 ^c	23.84±0.18 ^e	26.81±0.21 ^b	24.42±0.20 ^d
Amylopectin	52.28±0.30 ^e	49.96±0.27 ^c	50.53±0.29 ^c	47.64±0.26 ^a	51.15±0.28 ^d	51.21±0.28 ^d
Resistant Starch	3.42±0.08 ^a	4.28±0.08 ^b	4.62±0.09 ^b	5.18±0.10 ^a	3.86±0.07 ^c	4.06±0.08 ^c

YF = (100% Yam Flour), **YAF** = (95% Yam Flour and 5% African Yam Beans Flour), **UAF** = (95% Unripe Plantain Flour, and 5% yam beans), **YUA 1** = (80% Yam Flour, 10% Unripe Plantain Flour, 10% African yam beans), **YUA 2**=(60% Yam flour, 25% Unripe plantain flour and 15% African Yam Beans), **UPF** = (100% Unripe Plantain flour). Values are expressed as mean ± SD (n=3). Means with different superscripts within the same row are significantly different (p<0.05)

Table 8: Anti-Nutritional Composition

PARAMETERS	YF	YAF	UAF	YUA-1	YUA-2	UPF
Phytate(Mg/100g)	18.42±0.30 ^f	32.86±0.38 ^d	41.28±0.42 ^c	49.82±0.48 ^a	28.64±0.35 ^e	22.46±0.32 ^f
Oxalate (Mg/100g)	12.84±0.22 ^e	18.48±0.26 ^c	21.36±0.28 ^b	24.82±0.30 ^a	15.62±0.24 ^d	14.28±0.23 ^d
Tanin (Mg/100g)	6.24±0.12 ^e	9.82±0.16 ^c	11.64±0.18 ^b	13.82±0.20 ^a	8.46±0.14 ^d	5.48±0.11 ^e
Saponin (Mg/100g)	2.18±0.06 ^e	4.18±0.09 ^c	5.26±0.10 ^b	6.42±0.12 ^a	3.42±0.08 ^d	2.06±0.06 ^e
Trypsin Inhibitor(Tiu/Mg)	0.62±0.02 ^e	1.04±0.03 ^c	1.26±0.04 ^b	1.52±0.05 ^a	0.86±0.03 ^d	0.58±0.22 ^e
HCN (mg/kg)	0.58±0.02 ^b	0.82±0.3 ^a	0.72±0.02 ^{ab}	0.64±0.02 ^b	0.56±0.02 ^b	0.96±0.03 ^c

YF = (100% Yam Flour), **YAF** = (95% Yam Flour and 5% African Yam Beans Flour), **UAF** = (95% Unripe Plantain Flour, and 5% yam beans), **YUA 1** = (80% Yam Flour, 10% Unripe Plantain Flour, 10% African yam beans), **YUA 2**=(60% Yam flour, 25% Unripe plantain flour and 15% African Yam Beans), **UPF** = (100% Unripe Plantain flour). Values are expressed as mean ± SD (n=3). Means with different superscripts within the same row are significantly different (p<0.05)

DISCUSSION

The proximate composition of the instant pounded yam flour formulations demonstrated clear differences associated with the incorporation of unripe plantain and African yam bean (AYB) flour. Moisture content ranged from 7.34% in YUA 1 to 8.21% in YF. The relatively low moisture contents recorded across all the formulations are desirable for an instant flour product because low residual moisture generally favours storage stability by reducing the availability of water for microbial growth and chemical deterioration. The reduction in moisture from 8.21% in the 100% yam flour control to 7.34% in YUA 1 also suggested that the processing and formulation treatments produced flours with comparatively low moisture levels. The values obtained were within the range reported for composite flours containing African yam bean, indicating that the formulated products had moisture characteristics compatible with dry flour storage. Previous research has similarly shown that processing conditions and raw-material composition can significantly influence the moisture and other proximate characteristics of plantain-based flours (Udomkun et al., 2021).

Ash content increased progressively from 1.84% in YF to 2.48% in YUA 1, while UAF, YUA 2 and UPF recorded 2.23%, 2.06% and 2.12%, respectively. The relatively higher ash contents of the composite formulations, particularly YUA 1, suggested an improvement in the mineral-rich fraction of the flour following incorporation of AYB and unripe plantain. This observation was consistent with the mineral results, which showed appreciable increases in several mineral elements in the composite samples. Since ash represents the inorganic residue remaining after combustion, its increase generally indicates greater mineral contribution to the food material. Similar increases in ash and mineral-related nutritional quality have been reported in composite flour systems incorporating African yam bean.

Crude protein showed the most pronounced nutritional improvement following AYB incorporation. YF contained 6.54% protein, whereas YAF, UAF, YUA 1 and YUA 2 contained 7.82%, 10.48%, 13.26% and 8.12%, respectively. Thus, YUA 1, containing 10% AYB, produced the highest protein value. In contrast, UPF, which contained no AYB, had the lowest protein content of 4.21%. The pattern strongly indicated that African yam bean contributed substantially to protein enrichment of the composite flour. This is nutritionally important because yam and plantain are predominantly carbohydrate-based staples, while AYB is a protein-rich legume. Studies on processed AYB flour have similarly demonstrated its potential as a nutrient-dense ingredient for composite food formulations. Igboke et al. (2024), for example, reported appreciable protein levels in processed AYB flours and concluded that thermal processing did not eliminate their potential as functional and nutrient-rich food ingredients.

The protein response also indicated that the effect of AYB was dependent on the proportion of other ingredients in the blend. Although YUA 2 contained the highest AYB level at 15%, its protein content (8.12%) was lower than the 13.26% recorded for YUA 1. This suggests that the formulation effect could not be attributed solely to AYB percentage and may also have been influenced by the relative proportions and intrinsic composition of yam and unripe plantain. Nevertheless, the substantially higher protein contents of the AYB-containing samples compared with the 100% unripe plantain control demonstrated the potential of AYB fortification to improve the protein density of instant pounded yam flour.

Crude fat increased from 0.82% in YF to 2.76% in YUA 1. YAF, UAF and YUA 2 recorded 1.42%, 2.08% and 1.14%, respectively, whereas UPF had the lowest value of 0.68%. The increase in fat in AYB-containing formulations could be attributed largely to the lipid contribution of the legume. The relatively higher fat content of YUA 1 was also consistent with its comparatively high protein and ash contents, suggesting that this formulation received a greater contribution from the nutrient-dense legume component. However, the low overall fat levels across the formulations remained advantageous for a dry instant flour product because lower lipid content may reduce the risk of oxidative rancidity during storage.

Crude fibre increased from 1.62% in YF to 3.48% in YUA 1. The AYB-containing formulations generally exhibited higher fibre levels than the yam control, with UAF recording 2.86% and YUA 2 recording 2.08%. This increase suggested that AYB and unripe plantain contributed appreciably to the fibre fraction of the flour. Fibre enrichment is nutritionally relevant because dietary fibre contributes to gastrointestinal function and may influence the physiological response to carbohydrate-rich foods. The result is also compatible with previous reports that composite flour incorporation with AYB can improve fibre content and other nutritional attributes.

Carbohydrate content showed the opposite trend to protein, fat and fibre. YF had the highest carbohydrate content (80.97%), followed by UPF (82.77%), while YUA 1 had the lowest value (70.68%). The reduction in carbohydrate concentration in AYB-containing blends was expected because carbohydrate-rich yam and plantain were partially replaced by the protein- and fibre-containing legume flour. The result therefore demonstrated a nutritionally meaningful shift from a predominantly carbohydrate-based flour towards a more diversified nutrient composition following incorporation of AYB.

Overall, the proximate composition results indicated that composite formulation, particularly the inclusion of AYB, modified the nutritional profile of the instant pounded yam flour. YUA 1 appeared particularly promising because it combined relatively high protein (13.26%), fat (2.76%), ash (2.48%) and fibre (3.48%)

with a reduced carbohydrate content of 70.68%. These changes are consistent with the established potential of African yam bean as an ingredient for improving the nutritional quality of cereal- and tuber-based foods.

The functional properties of the flour samples showed considerable variation among the formulations, indicating that the incorporation of AYB and unripe plantain modified the hydration, density and reconstitution characteristics of the flour. Water absorption capacity (WAC) increased from 2.18 g/g in YF to 2.92 g/g in YUA 1. UAF recorded 2.67 g/g, while YAF and YUA 2 recorded 2.41 and 2.38 g/g, respectively. The highest WAC in YUA 1 suggested that the combination of yam, unripe plantain and AYB at 80:10:10 provided a matrix with greater capacity to bind water.

The increased WAC of the composite formulations may be associated with the presence of protein, fibre and other hydrophilic constituents contributed by AYB. Protein molecules contain polar groups capable of interacting with water, while dietary fibre can retain water through physical entrapment and hydrogen bonding. The progressive increase in WAC from YF to YUA 1 therefore supported the observed improvement in protein and fibre contents. Similar enhancement of water absorption has been reported when AYB was incorporated into composite flour systems.

Oil absorption capacity also increased from 1.36 g/g in YF to 1.88 g/g in YUA 1. This suggested that incorporation of AYB improved the ability of the flour matrix to bind lipid. The increase may be associated with the presence of non-polar side chains in proteins and other components capable of interacting with oil. Higher oil absorption capacity may be beneficial in food formulations because it can contribute to flavour retention and improved mouthfeel of reconstituted products. The finding agrees with studies showing that incorporation of AYB can improve the functional characteristics of composite flours, particularly water and oil absorption.

Swelling capacity decreased from 6.85% in YF to 5.74% in YUA 1, while UPF recorded 6.58%. The reduction suggested that the presence of AYB and the changes in starch composition affected the ability of the flour particles to swell during hydration. Swelling is closely related to starch structure, amylose–amylopectin ratio and the interaction of starch with proteins and fibre. Thus, the lower swelling capacity of some composite formulations may reflect increased interactions between starch and non-starch components. Similar differences in hydration-related properties have been reported among plantain and composite flours, with unripe plantain flour exhibiting distinctive water-holding and starch-related properties.

Solubility increased from 8.42% in YF to 11.54% in YUA 1. The relatively high solubility of YUA 1 indicated that a greater proportion of its flour constituents became dispersible in water. This characteristic is particularly desirable in instant food products because rapid hydration and dispersion facilitate easier preparation and more uniform reconstitution. The result also suggests that the combined processing of the raw materials and the formulation ratio influenced the interaction between starch, protein and other soluble components.

Bulk density increased from 0.71 g/mL in YF to 0.82 g/mL in YUA 1. The relatively higher density of YUA 1 indicated closer packing of flour particles or differences in particle characteristics following incorporation of AYB and plantain. Bulk density is important for packaging, transportation and storage because it determines the amount of flour that can be accommodated in a given package volume. The values obtained were within the range reported for African yam bean-containing composite flour systems.

Foam capacity and emulsion capacity also increased substantially with composite formulation. Foam capacity increased from 3.8% in YF to 12.8% in YUA 1, while emulsion capacity increased from 24.4% to 38.5%. These changes may be related to the increased protein content of the AYB-containing samples because proteins can adsorb at air–water and oil–water interfaces, thereby improving foaming and emulsifying behaviour. The particularly high values recorded for YUA 1 were consistent with its highest protein content. These properties could be useful in food systems where improved interfacial activity is desirable.

Least gelation concentration decreased from 12.2% in YF to 6.0% in YUA 1. A lower least gelation concentration indicates that less flour was required to form a stable gel under the conditions of the test. The reduced value observed in the composite formulation may reflect changes in protein concentration, starch composition and interactions among the flour constituents. From a product-development perspective, this could contribute to improved body and cohesiveness during reconstitution.

Taken together, the functional-property results showed that YUA 1 generally displayed the most pronounced functional enhancement, particularly in WAC, OAC, solubility, bulk density, foam capacity and emulsion capacity. This suggests that moderate incorporation of AYB together with a limited amount of unripe plantain produced a flour with favourable hydration and reconstitution characteristics.

The pasting characteristics demonstrated substantial differences among the flour formulations. Peak viscosity ranged from 2,068 RVU in UPF to 2,848 RVU in YF. YUA 2 recorded 2,764 RVU, while UAF, YUA 1 and YAF recorded 2,528, 2,294 and 2,124 RVU, respectively. The high peak viscosity of YF suggested greater swelling and water uptake of its starch granules during heating. The reduction in peak viscosity following AYB and plantain incorporation indicated that non-starch components interfered with starch swelling and/or diluted the starch concentration.

The reduction in peak viscosity in the composite flours is consistent with the principle that proteins and fibre can compete with starch for available water and restrict granule swelling. Studies involving composite flours containing AYB have similarly reported substantial changes in peak and other pasting parameters following legume incorporation.

Trough viscosity decreased from 1,882 RVU in YF to 1,474 RVU in UPF. The relatively high trough value of YF suggested greater resistance of the yam starch paste to breakdown during continued heating and shear. YUA 2, however, recorded 1,838 RVU, indicating that the formulation retained relatively high paste stability despite incorporation of plantain and AYB.

Breakdown viscosity was highest in YF (966 RVU) and lowest in UPF (594 RVU). Breakdown reflects the degree of susceptibility of swollen starch granules to disintegration during heating and shear. The higher breakdown value of YF therefore suggested that its swollen starch granules were more susceptible to structural disruption, whereas the lower values in the composite and plantain-rich samples indicated comparatively greater resistance to breakdown. The observed pattern agrees with the understanding that flour composition and processing influence starch swelling and paste stability. Udomkun et al. (2021) similarly reported significant variation in peak and breakdown viscosities of plantain flours as affected by raw material characteristics and processing conditions.

Final viscosity ranged from 2,642 RVU in UPF to 3,588 RVU in YF. The high final viscosity of YF indicated a strong ability to form a viscous paste after cooling. YUA 2 also recorded a relatively high final viscosity of 3,496 RVU, suggesting that this formulation retained substantial paste-forming capacity. Setback viscosity followed a similar pattern, with YF recording the highest value (1,706 RVU) and UPF the lowest (1,168 RVU). Setback is associated with reassociation of starch molecules during cooling and is often related to retrogradation tendency. Thus, the higher setback of YF suggested greater starch reassociation during cooling compared with the other formulations.

Peak time ranged from 5.42 min in UPF to 5.71 min in YF. The relatively narrow range indicated that all formulations reached peak viscosity within a comparable period. The slightly shorter peak time of UPF suggested somewhat faster development of maximum viscosity, whereas the longer time recorded for YF indicated a slightly slower progression to peak viscosity.

Pasting temperature varied from 82.6 °C in YF to 83.8 °C in UPF. The relatively small variation indicated that the formulations had comparable thermal requirements for the onset of pasting. The slightly higher pasting temperature of UPF suggested greater resistance to initial starch gelatinization compared with YF. Overall, the pasting results demonstrated that incorporation of AYB and unripe plantain altered starch

swelling, paste stability and retrogradation behaviour without eliminating the ability of the formulations to develop high-viscosity pastes.

The mineral composition showed that incorporation of AYB and unripe plantain substantially modified the mineral profile of the instant pounded yam flour. Calcium increased from 26.42 mg/100 g in YF to 52.74 mg/100 g in YUA 1. Magnesium followed a similar pattern, increasing from 28.54 mg/100 g in YF to 56.48 mg/100 g in YUA 1. Phosphorus increased from 96.42 mg/100 g in YF to 164.82 mg/100 g in YUA 1. These increases indicated that composite formulation, particularly the inclusion of AYB, improved the mineral density of the flour.

The increase in calcium, magnesium and phosphorus was nutritionally relevant because these minerals perform important physiological functions, including maintenance of skeletal structure, neuromuscular activity, energy metabolism and cellular function. The mineral enhancement observed in the AYB-containing formulations supports previous reports that incorporation of African yam bean can improve the mineral quality of composite flour products.

Iron increased from 1.82 mg/100 g in YF to 4.18 mg/100 g in YUA 1, while zinc increased from 1.12 to 2.42 mg/100 g over the same formulations. Manganese also increased from 0.46 to 0.92 mg/100 g. Copper showed a similar increase from 0.18 mg/100 g in YF to 0.42 mg/100 g in YUA 1. The simultaneous increases in these trace minerals further demonstrated the nutritional contribution of AYB to the composite flour.

Sodium ranged from 17.84 mg/100 g in UPF to 23.82 mg/100 g in YUA 1. Potassium was comparatively high across all samples, ranging from 389.82 to 436.18 mg/100 g. The high potassium concentration was particularly noteworthy because potassium is an important intracellular electrolyte involved in fluid balance, nerve transmission and muscle function. The generally higher mineral values of the composite formulations indicated that AYB incorporation provided more than protein enrichment; it also enhanced the mineral density of the product.

The overall mineral results therefore suggested that YUA 1 provided the strongest mineral enhancement among the formulations, particularly for calcium, magnesium, phosphorus, iron, zinc, copper and manganese. This finding strengthens the nutritional justification for incorporating AYB into yam- and plantain-based staple foods.

The starch composition revealed important changes associated with formulation. Total starch ranged from 71.48% in YUA 1 to 77.96% in YUA 2, while YF contained 77.82%. The relatively lower starch content of YUA 1 was consistent with its higher protein, fat, fibre and ash contents, indicating dilution of the starch fraction by the non-starch components introduced through AYB and plantain.

Amylose content ranged from 23.84% in YUA 1 to 28.54% in YF. The reduction in amylose in the composite formulations may influence gelatinization, swelling and retrogradation behaviour. Since amylose contributes strongly to starch reassociation during cooling, changes in amylose content can partly explain the differences observed in final and setback viscosities among the formulations.

Resistant starch increased from 3.42% in YF to 5.18% in YUA 1. This was an important nutritional improvement because resistant starch escapes digestion in the small intestine and can reach the colon, where it may be fermented by the gut microbiota. The relatively high resistant starch content of the composite formulations may partly reflect the contribution of unripe plantain, which is known to possess a starch structure associated with relatively high amylose and resistant-starch characteristics. Udomkun et al. (2021) reported that unripe plantain flours exhibited high amylose and resistant-starch-related properties.

The increase in resistant starch was particularly notable in YUA 1 despite its lower total starch content. This indicates that the nutritional quality of the starch fraction was altered rather than merely its quantity. Consequently, the formulation may provide a potentially favourable balance between available carbohydrate and resistant starch.

The antinutritional composition demonstrated that AYB incorporation increased the concentrations of several measured antinutritional factors. Phytate increased from 18.42 mg/100 g in YF to 49.82 mg/100 g in YUA 1, while oxalate increased from 12.84 to 24.82 mg/100 g. Tannin increased from 6.24 to 13.82 mg/100 g, and saponin increased from 2.18 to 6.42 mg/100 g. Trypsin inhibitor activity increased from 0.62 TIU/mg in YF to 1.52 TIU/mg in YUA 1.

The increase in these compounds was expected because African yam bean is a leguminous seed that naturally contains several antinutritional compounds. Previous studies have documented the occurrence of phytate, tannins, oxalate and trypsin inhibitors in AYB and have demonstrated that processing can substantially reduce their concentrations.

Importantly, the present results should not be interpreted simply as evidence that AYB incorporation was undesirable. Rather, they demonstrate the need to balance nutritional enrichment with adequate processing. The AYB used in the present study was subjected to soaking and boiling before drying and milling, and the resulting antinutritional levels were substantially lower than those reported for raw AYB in some studies. Processing, particularly soaking and heat treatment, has been demonstrated to reduce phytate, tannins, oxalate, trypsin inhibitors and related antinutritional factors in AYB.

HCN values were generally low, ranging from 0.56 to 0.96 mg/kg. YAF recorded 0.82 mg/kg, while UPF had the highest value of 0.96 mg/kg. The relatively low HCN concentrations across the formulations suggested that cyanogenic compounds did not accumulate substantially as a consequence of the composite formulation. However, because antinutritional-factor concentrations are influenced by raw material, cultivar and processing conditions, appropriate processing and analytical monitoring remain important in future product development.

Overall, the antinutritional results indicate that increasing AYB incorporation improved nutritional characteristics but also increased certain antinutritional constituents. This represents an important formulation consideration. The objective should therefore be to identify an inclusion level that provides meaningful protein and mineral enrichment without producing undesirable increases in antinutritional factors.

The sensory evaluation demonstrated that the nutritional and functional improvements associated with composite formulation were accompanied by changes in consumer acceptability. The 100% yam flour control, YF, recorded high scores across the sensory attributes, with colour, aroma, taste, smoothness, mouldability and elasticity values of 8.72, 8.46, 8.58, 8.62, 8.54 and 8.48, respectively. Its overall acceptability score was 8.64, indicating that the control remained highly acceptable to the panelists.

YAF also demonstrated high sensory acceptance, with an overall acceptability score of 8.48. This indicated that the incorporation of 5% AYB into yam flour produced only a limited sensory deviation from the control. The result is important because it demonstrates that low-level AYB fortification can improve nutritional quality while retaining desirable sensory characteristics.

As the formulation became more complex, sensory scores generally declined. UAF, YUA 1 and YUA 2 showed lower scores than YF and YAF for several attributes. This trend was particularly evident for taste, smoothness and elasticity. The reduction may be associated with the characteristic flavour, colour and textural effects of AYB and unripe plantain. Legume incorporation can modify aroma and taste because of its characteristic volatile and non-volatile compounds, while plantain and fibre can influence the smoothness and cohesiveness of reconstituted dough.

Nevertheless, YUA 1 maintained a relatively high overall acceptability score of 8.22, suggesting that the formulation remained well accepted despite containing 10% AYB and 10% unripe plantain. Its overall acceptability was higher than that of YUA 2 (7.66), indicating that increasing the proportion of the composite ingredients beyond the YUA 1 level may progressively reduce sensory acceptance. This finding is important from a product-development perspective because the formulation with the highest nutritional enhancement is not necessarily the formulation with the highest consumer acceptance.

The relatively lower sensory scores recorded for UPF, particularly for taste, smoothness and elasticity, further demonstrated the importance of yam in maintaining the characteristic sensory properties expected of pounded yam. The result suggests that although unripe plantain can contribute nutritional and functional benefits, complete replacement of yam may compromise the sensory characteristics associated with conventional pounded yam.

The sensory findings are broadly consistent with previous research showing that AYB incorporation can improve the nutritional and functional quality of plantain-based products while sensory acceptance depends on the level of substitution. Studies on plantain–AYB flour blends have reported improved nutritional and functional characteristics with AYB inclusion, while moderate inclusion levels can retain acceptable sensory properties.

Taken together, the findings demonstrated that incorporation of African yam bean and unripe plantain substantially modified the nutritional, functional, pasting, mineral, starch, antinutritional and sensory characteristics of instant pounded yam flour. The changes were not uniformly positive or negative; rather, they reflected a nutritional–technological trade-off that is central to composite flour formulation.

YUA 1 was particularly notable because it provided the highest protein content (13.26%), highest fat (2.76%), highest ash (2.48%), highest crude fibre (3.48%), high mineral concentrations and the highest resistant starch level (5.18%). It also recorded the highest WAC, OAC, solubility, bulk density, foam capacity and emulsion capacity among the formulations. However, it simultaneously showed relatively high levels of phytate, oxalate, tannin, saponin and trypsin inhibitor activity. Thus, while YUA 1 demonstrated considerable potential as a nutritionally enhanced instant pounded yam flour, the antinutritional profile should be considered in determining the optimum formulation.

YAF provided a different balance, with only 5% AYB incorporation and an overall acceptability score of 8.48. Its relatively modest changes in nutritional composition, combined with high sensory acceptance, suggest that it may be suitable where consumer acceptability is prioritized. YUA 1, on the other hand, appeared more promising where the objective is to maximize nutritional and functional enhancement while retaining acceptable sensory quality.

The findings therefore support the use of yam, unripe plantain and African yam bean as complementary raw materials for developing nutrient-enhanced instant pounded yam flour. Previous research has similarly demonstrated that AYB can improve the nutritional and functional characteristics of composite flour products, while unripe plantain contributes distinctive starch and functional properties.

CONCLUSION

The study demonstrated the feasibility of producing acceptable instant pounded yam flour from yam–unripe plantain composite blends fortified with African yam bean (*Sphenostylis stenocarpa*) flour. The different formulations produced variations in their nutritional, functional, pasting, mineral and sensory characteristics, confirming that the proportion of each raw material influences the quality of the final product.

Sensory evaluation revealed that the 100% yam flour control (PDY) had the highest overall acceptability, while among the fortified formulations, PYA (95% yam flour and 5% African yam bean flour) recorded a particularly high overall acceptability score of 8.48, indicating that low-level African yam bean incorporation can be achieved without substantial deterioration of desirable pounded-yam characteristics. PXY (80% yam, 10% unripe plantain and 10% African yam bean) also showed good sensory performance, with an overall acceptability score of 8.22, suggesting potential for the development of a nutritionally diversified composite product.

However, higher incorporation of African yam bean and plantain, particularly in PYZ, was associated with lower sensory scores for several attributes. This indicates that although increased incorporation may enhance nutritional diversification, excessive substitution can adversely affect the characteristic colour, taste, smoothness, mouldability and elasticity expected of pounded yam.

Overall, moderate incorporation of African yam bean, particularly at 5–10%, appears more suitable for maintaining the sensory quality of instant pounded yam flour. The study therefore concludes that yam–plantain–African yam bean composite flour has considerable potential as a convenient and nutritionally improved instant pounded yam product, while appropriate formulation is essential to achieve a balance between nutritional enhancement, technological functionality and consumer acceptability.

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