GSC Biological and Pharmaceutical Sciences

eISSN: 2581-3250 CODEN (USA): GBPSC2

Cross Ref DOI: 10.30574/gscbps

Journal homepage: https://gsconlinepress.com/journals/gscbps/

(RESEARCH ARTICLE)

Nutritional and Functional Implications of Yellow Yam-Soybean Composite Flour for Food Formulation: Evidence from Kogi State, Nigeria

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GSC Biological and Pharmaceutical Sciences, 2026, 34(01), 007-018

Publication history: Received on 22 November 2025; revised on 03 January 2026; accepted on 05 January 2026

Article DOI: https://doi.org/10.30574/gscbps.2026.34.1.0527

Abstract

Yellow yam (*Dioscorea cayenensis*) is widely consumed in West Africa but remains nutritionally limited by its low protein and essential amino acid content. Soybean (*Glycine max*), a legume rich in high-quality protein and functional nutrients, offers a strategic fortification option. This study assessed the proximate composition, functional properties and amino-acid profile of yellow yam–soybean composite flours formulated to enhance nutritional value and support food-based approaches to malnutrition reduction. Yellow yam and soybean flours were produced using standard procedures and blended at ratios of 100:0, 90:10, 80:20, 70:30 and 60:40 (YYF: SBF). Soybean fortification substantially improved nutritional quality: protein increased from 10.18% to 23.11%, while TEAA and TAA rose from 25.60 to 34.84 mg/100 g and 68.76 to 94.72 mg/100 g, respectively. Functional properties such as water and oil absorption, solubility, emulsifying activity and foaming capacity increased, whereas swelling power decreased. Yellow yam–soybean composite flour provides enhanced nutritional density, superior amino-acid balance, and improved functional behaviour, indicating strong potential for developing nutrient-dense foods in yam-dependent regions.

Keywords: Proximate Composition; Functional Properties; Amino Acid Profile; Soybean; Yellow Yam; Composite Flour.

1. Introduction

In sub-Saharan Africa, where protein-energy shortage and micronutrient insufficiency persist despite the abundance of carbohydrate-rich staples, food-based interventions continue to be essential for addressing malnutrition. In areas where they are grown, yams provide more than 200 kcal per day, making them one of the most significant tuber crops in West Africa. The yellow yam (*Dioscorea cayenensis*), which is extensively grown in Nigeria, is especially prized for its provitamin A carotenoids, potassium, dietary fibre, and starch. However, its significance as a balanced dietary source is limited by its inadequate amino acid profile and relatively low protein content [1]. The creation of composite flours using locally accessible legumes is one possible strategy to lessen these deficiencies [2].

Because it is extremely adaptable to local agro-ecologies and contains high-quality protein with all essential amino acids especially lysine, which is limited in yams and other starchy staples soybeans (*Glycine max*) make an excellent fortificant. In addition to protein, soybeans offer minerals, vitamins B, and unsaturated fatty acids that work together to improve the nutritional content of dishes made from yams [3]. Additionally, adding soybean flour to yellow yam flour enhances the functional qualities that govern the texture and acceptance of traditional food products, such as water absorption, emulsification and pasting characteristics [4].

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Nutrient-dense substitutes for conventional cereal or tuber-based staples have been successfully developed using composite flour technology. Yam and soy blends, for example, have been demonstrated to improve mineral availability, increase the protein efficiency ratio, and result in doughs with desired rheological qualities [5]. Considering the nutritional value of yellow yams in Kogi State and the complementary advantages of soybeans, assessing their combinations is useful from a practical and scientific standpoint.

Despite its nutritional significance and widespread use in West Africa, little research has been done on the use of yellow yam (*Dioscorea cayenensis*) as a basis material in composite flours. Industrial applications has been hampered by its weak baking and processing qualities. Similarly, although soybeans are known for having a high protein and vitamin content, there hasn't been much research done on how well they work with yam flour. By creating and evaluating a composite flour made from yellow yams and soybeans to improve nutritional quality and functional potential, this study seeks to close this gap. In order to provide a useful, nutrient-dense substitute for traditional cereal-based flours, this study presents a unique formulation that makes use of the complementary nutritional profiles of both yellow yams and soybeans. In order to provide evidence-based insights that could support food security, nutritional diversity, and industrial applications in areas that heavily rely on root crops, the invention entails a scientific evaluation of its proximate, mineral and amino acid content.

The purpose of this study is to evaluate the nutritional value of a composite flour prepared from Kogi-sourced soybeans and yellow yams. It specifically aims to ascertain the flour's functional characteristics, amino acid profile and proximate composition. The objective is to present evidence for the creation of culturally acceptable, nutrient-enhanced food products that can lessen malnutrition in cultures that depend on yams as a staple.

2. Experimental

2.1. Collection of samples

Yellow yams (*Dioscorea cayenensis*) were purchased for the study at the international market in Kogi State, Nigeria; other ingredients, such as soybeans (*Glycine max*), were purchased from the Kabba market. The samples were cleaned to remove dust, debris, stones and broken seeds. To be used later, they were all brought to the laboratory in sanitised polyethene bags.

2.2. Preparation of samples

2.2.1. Preparation of the yellow yam flour sample

The yellow yam tubers were cut into 2 cm pieces using a stainless-steel slicer. After that, the meat was gently roasted at 100 °C for 15 minutes to avoid browning. After being divided into 2 cm^3 cubes, the samples were left to air dry at room temperature for around 4 days. After being reduced to a fine powder, these samples were put in a polyethene bag that could be sealed and kept cold until further analysis.

2.2.2. Preparation of soybean flour

The soybean was cleaned to remove debris and other items. After being evenly distributed, the nuts were allowed to air dry at room temperature. The soybean was shelled with a nutcracker. This was then pounded until it was consistently thick using a mortar and pestle. The soybean was sealed in an airtight container after being further sieved through a 2.0 mesh sieve to produce an even more powdered texture.

2.2.3. Preparation of blends of yellow yam flour and Soybean flour

The following ratios of yellow yam flour to soybean were blended (%, w/w): 100:0, 90:10, 80:20, 70:30, and 60:40. A Kenwood mixer was used to help homogenize the samples so that they were uniform. To increase the doughnut's nutritious content, the formulation was made.

2.3. Determination of Proximate Composition

Standard analytical methods described by AOAC [6] were adopted for the determination of moisture content, crude protein, crude fibre, percentage fat and ash content. The carbohydrate content was calculated by difference.

2.4. Determination of Functional Properties

2.4.1. Dispersibility

Kulkarni *et al*. [7] devised a method for evaluating flour dispersibility. The identical measuring cylinder was filled with 10 grams of flour and 100 cm^3 of distilled water. The setup was vigorously shaken for one minute. The settled particle volume was measured 30 minutes later, as is customary. The number of settling particles was subtracted from 100. The dispersion percentage was used to express the difference.

2.4.2. Bulk Density

The bulk density was determined using the approach described by Arise *et al*. [8] A 100 cm^3 measuring cylinder was filled with 50 g of the sample. The measuring cylinder was then repeatedly tapped on a lab table until it achieved the desired volume. The bulk density was calculated using the following formula:

$$BD\ (g/cm^3) = \frac{Weight\ of\ sample}{Volume\ of\ sample\ after\ taping} \quad (1)$$

2.4.3. Water Absorption Capacity (WAC) and Solubility Index (SI)

The water absorption capacity of the flours in the sample was ascertained using the methods outlined by [9]. Ten centilitres of distilled water and one gram of flour samples (Mo) were weighed into a centrifuge tube. The contents of the centrifuge tube were shaken for half an hour in a KS 10 agitator. The mixture was centrifuged in a water bath (MEMMERT) for 30 minutes at 37°C and for 15 minutes at 5000 rpm. Before being measured, the resulting sediments (M_2) were dried to a constant weight (M_1) at 105°C. After that, the following formula was used to calculate WAC:

$$WAC\ (\%) = \frac{Weight\ of\ the\ water\ added\ to\ the\ sample - Weight\ of\ the\ water\ removed\ from\ sample}{Weight\ of\ flour\ sample} \times 100 \quad (2)$$

$$WSI\ (\%) = \frac{Weight\ of\ dried\ supernatant\ (g)}{Dry\ weight\ of\ flour\ (g)} \times 100 \quad (3)$$

2.4.4. Oil Absorption Capacity (OAC)

The sample's ability to absorb oil was assessed using methods developed by [9]. A 20 cm^3 centrifuge tube was filled with 1 g of the sample (M_o) and 10 cm^3 of oil, and the mixture was weighed. After two minutes of mixing in a vortex mixer, the slurry was centrifuged for thirty minutes at 4500 rpm while being kept at 28°C. The clear supernatant was decanted and discarded. The tube was weighed after any oil drops that had adhered to it were scraped off (M_1). The OAC was calculated as follows:

$$OAC\ (\%) = \frac{Weight\ of\ the\ oil\ added\ to\ the\ sample - Weight\ of\ the\ oil\ removed\ from\ the\ sample}{Weight\ of\ the\ flour\ sample} \times 100 \quad (4)$$

2.4.5. Swelling Capacity

Kaushal *et al*. [10] described the method. One gram of flour was placed inside a 10 cm^3 graduated cylinder. After adding 5 cm^3 of distilled water, the sample's volume was measured. The sample was left undisturbed in the water for an hour. Following swelling, the volume occupied was calculated and quantified as follows:

$$Swelling\ capacity = \frac{volume\ occupied\ by\ sample\ after\ swelling}{volume\ occupied\ by\ sample\ before\ swelling} \quad (5)$$

2.4.6. Foaming capacity

The foaming capacity (FC) of the flours was determined using the modified technique of Chandra *et al*. [11]. Three (3) g of sesame seed flour (raw or sprouted) were placed in a 50 mL graduated cylinder previously dried in the oven. Then, thirty (30) mL of distilled water was added to the sample to facilitate the dispersion of the flour in the test tube, and the volume was noted (volume before homogenization). Then, the test tube was vigorously shaken by hand, and the new volume was read on the test piece (volume after homogenization). The volume of the foam obtained was calculated by differentiating between the volume after homogenization and the volume before homogenization. The foaming capacity was calculated from the following formula:

$$FC\ (\%) = \frac{(V_{after} - V_{before})}{V_{before}} \times 100 \quad (6)$$

FC: Foaming capacity, V_{before}: Volume before homogenization (mL), V_{after}: Volume after homogenization (mL)

2.4.7. Emulsifying activity index

Modified method by [12] was employed in our study to show the emulsifying property of the composite flour sample. 20 ml of 0.1% (w/v) slurred sample in 0.05 mol/L phosphate buffer with pH 7.0 was homogenised with 6.60 ml refined soybean oil for 1 min in a high-speed blender at 10000 rpm. Immediately after homogenization, aliquots of 20 ml emulsion were diluted to 5 ml with 0.1% SDS. The absorbance of this mixture at 500 nm was recorded at a spectrophotometer. The EAI was calculated as follows:

$$EAI\ (m^2/g) = 2T\left[\frac{(A\times D)}{C\times ø\times L\times 10}\right] \quad …….. \quad (7)$$

where T = 2.303, A = observed absorbance, D = dilution factor, ø = volume fraction of the dispersed phase (oil), C = weight of proteins per unit volume (g/L) of aqueous phase before the emulsion was formed and L = path length of the cuvette (cm).

2.4.8. Least gelation concentration

The least gelation concentration (LGC) was evaluated using a method modified by Chandra *et al*. [11]. The flour dispersions of 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 30% (w/v) prepared in 5 mL of distilled water were heated at 90 °C for 1 h in a water bath. The contents were cooled under tap water and kept for 2 h at 10±2 °C. The least gelation concentration was determined method given as that concentration at which the sample from the inverted tube did not slip.

2.5. Determination of Amino Acid Profiles

This was evaluated by employing a Soxhlet extractor to extract 3.00 g of the material in petroleum ether (40–60°C) for six hours [13]. A glass ampoule was filled with 30.00 mg of defatted samples and 7.00 cm^3 of 6.00 mol/dm^3 hydrochloric acid. Nitrogen was released after oxygen was put into the ampoule to stop some amino acids from oxidising during hydrolysis. The ampoule was sealed with a Bunsen flame, heated to 105°C for 22 hours, then allowed to cool, broken at the tip and its contents filtered. The filtrate was vacuumed and evaporated to dryness at 40°C in a revolving evaporator. The residue was stored in a plastic bottle in the deep freezer for a full day after being dissolved in 5.00 cm^3 of acetate buffer (pH 2.0). Five to ten microliters of the hydrolysate were added to the Technicon Sequential Multi-Sample (TSM) amino acid analyser. This was poured into the analyser's cartridge, and the analysis proceeded for 76 minutes.

2.6. Statistical Analysis

The obtained research results were subjected to statistical analysis using mean standard deviation analysis of variance (ANOVA) as described by Duncan's multiple range test to determine the level of significance between different samples and significance was set at $p \leq 0.05$.

3. Results

3.1. Formulation of yellow yam and soybean blend result

Table 1, shows the formulation of the sample composite. The selected ratios (100:0, 90:10, 80:20, 70:30 and 60:40) provides a range of proportions to evaluate the impact on the fortified yam's nutritional composition.

Table 1 Sample codes for yellow yam and soybean formulation

Sample	YYF (%)	SBF (%)
EOG	100	0
AGF	90	10
YPY	80	20
EII	70	30
AUA	60	40

Notice: YYF: Yellow yam flour, SBF: Soybean flour, GOE: (YYF 100:0 SBF), AGF: (YYF 90:10 SBF), YPY: (YYF 80:20 SBF), EII: (YYF 70:30 SBF), AUA: (YYF 60:40 SBF)

3.2. Proximate composition of yellow yam-soybean flour composite result

As the percentage of soybean flour rises from 0% (EOG) to 40% (AUA), the proximate composition data (Table 2) demonstrate systematic and nutritionally significant variations. The moisture content gradually dropped from 5.58±0.35% (EOG) to 3.31±0.18% (AUA). Crude protein rose from 10.18±0.18% (EOG) to 23.11±0.57% (AUA). Crude fat increased concurrently from 15.88±0.55% (EOG) to 18.99±0.44% (AUA). There was a small decrease in crude fiber (8.35±0.22% to 6.38±0.14%) and ash (4.04±0.28% to 2.10±0.19%). The carbohydrate concentration dropped from 58.33±0.51% to 46.13±0.52%.

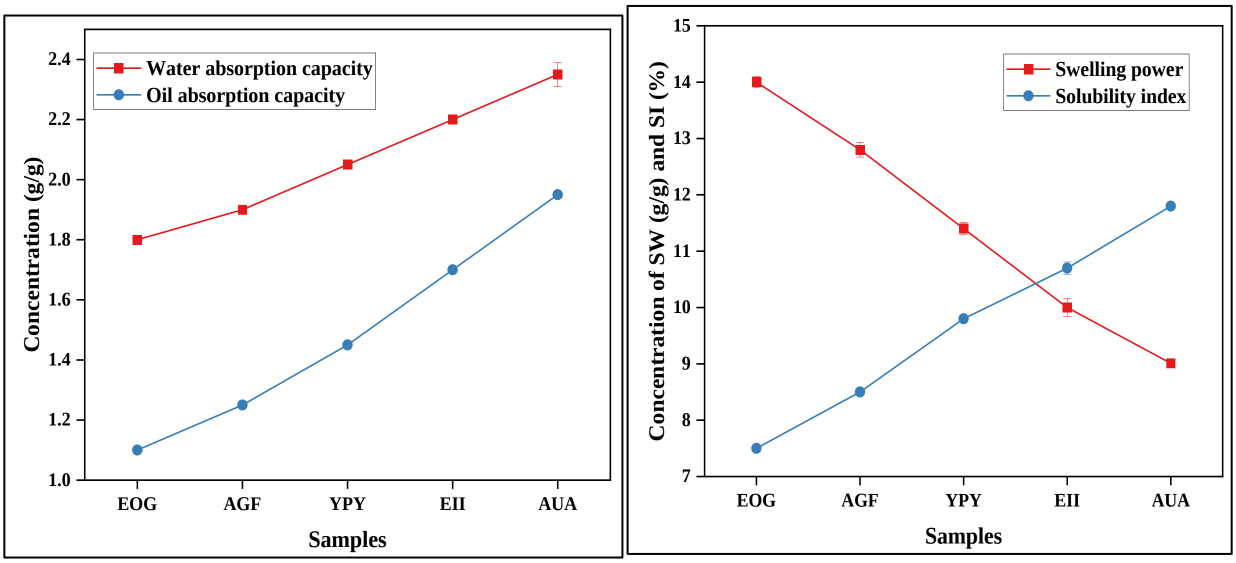
Table 2 Proximate composition of yellow yam and soybean flour composite

Sample	Moisture (%)	Ash (%)	Fat (%)	Fibre (%)	Protein (%)	Carbohydrate (%)
EOG	5.58±0.35	4.04±0.28	15.88±0.55	8.35±0.22	10.18±0.18	58.33±0.51
AGF	4.66±0.44	3.14±0.22	16.28±0.37	7.82±0.13	13.39±0.42	54.78±0.49
YPY	4.27±0.21	3.09±0.12	16.65±0.48	7.34±0.11	17.72±0.51	51.66±0.43
EII	3.66±0.11	2.84±0.15	17.67±0.56	6.86±0.31	19.84±0.48	49.02±0.31
AUA	3.31±0.18	2.10±0.19	18.99±0.44	6.38±0.14	23.11±0.57	46.13±0.52

Notice: YYF: Yellow yam flour, SBF: Soybean flour, GOE: (YYF 100:0 SBF), AGF: (YYF 90:10 SBF), YPY: (YYF 80:20 SBF), EII: (YYF 70:30 SBF), AUA: (YYF 60:40 SBF)

3.3. Functional properties of yellow yam-soybean flour composite result

The rise in the percentage of soybean flour (SBF) in yellow-yam flour (YYF) composites, has brought about a consistent change in their functional behaviours as seen in the functional property dataset (Figure 1). Oil absorption capacity (OAC) grew from 1.10±0.00 to 1.95±0.01 g oil/g flour, while water absorption capacity (WAC) gradually increased from 1.80±0.01 to 2.35±0.04 g water/g flour. Swelling power (SP) dropped from 14.0±0.10 g/g (EOG) to 9.01±0.01 g/g (AUA), but solubility index (SI) rose from 7.50±0.05% to 11.80±0.05%. dispersibility increased from 65±0.13% to 78.11±0.20% and bulk density increased slightly from 0.58±0.00 to 0.65±0.01 g/mL. Foaming capacity (FC) and emulsifying activity index (EAI) both significantly increased when soy content increased (FC: 10 to 45.01%; EAI: 18.01 to 46.10 m^2/g), whereas least gelation concentration (LGC) increased from 6.0±0.03% to 9.5±0.10%.



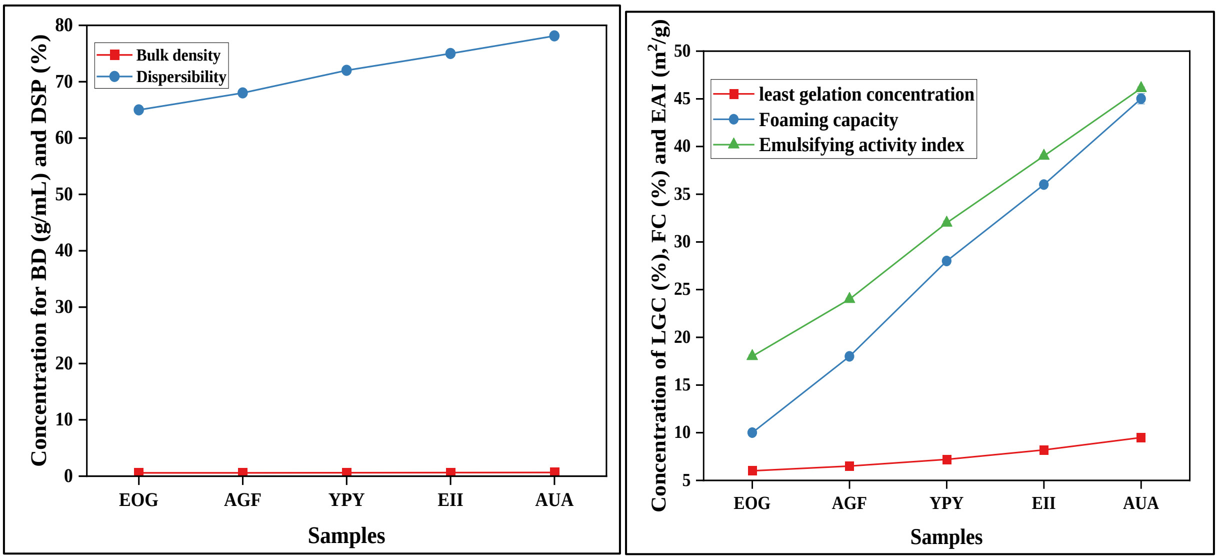


Figure 1 Functional properties of yellow yam and soybean flour composite

3.4. Amino acid profile of yellow yam-soybean flour composite result

Yellow-yam flour's protein quantity and quality clearly improve in a dose-dependent manner as it is fortified with soybean flour as shown in Tables 4-5. total essential amino acids (TEAA) increased from 25.60 to 34.84 mg/100 g, total amino acids (TAA) increased from 68.76 to 94.72 mg/100 g, and the BCAA pool increased from 12.90 to 16.43 mg/100 g across the formulations.

Table 3 Amino acid profile of yellow yam and soybean flour composite

S/N	Amino Acid	EOG (mg/100g)	AGF (mg/100g)	YPY (mg/100g)	EII (mg/100g)	AUA (mg/100g)
1	Isoleucine	3.20±0.04	3.46±0.02	3.73±0.04	3.99±0.01	4.25±0.02
2	Leucine	5.80±0.05	6.18±0.05	6.56±0.05	6.94±0.02	7.32±0.03
3	Lysine	2.10±0.02	2.83±0.01	3.56±0.01	4.29±0.01	5.02±0.02
4	Methionine	1.30±0.01	1.38±0.01	1.46±0.00	1.54±0.01	1.62±0.00
5	Phenylalanine	3.90±0.02	4.02±0.02	4.15±0.02	4.27±0.03	4.40±0.02
6	Threonine	2.60±0.01	2.87±0.03	3.14±0.00	3.41±0.01	3.68±0.01
7	Tryptophan	0.60±0.00	0.79±0.00	0.98±0.02	1.17±0.01	1.36±0.00
8	Valine	3.90±0.01	4.14±0.02	4.38±0.04	4.62±0.03	4.86±0.02
9	Histidine	1.80±0.01	1.93±0.01	2.07±0.01	2.21±0.01	2.35±0.01
10	*Alanine	4.60±0.01	4.63±0.02	4.66±0.02	4.69±0.02	4.72±0.02
11	*Aspartic Acid	8.90±0.03	9.58±0.05	10.26±0.10	10.94±0.55	11.62±0.13
12	*Glutamic Acid	12.40±0.05	13.82±0.10	15.24±0.55	16.66±0.15	18.08±0.11
13	*Glycine	3.50±0.02	3.61±0.05	3.72±0.02	3.83±0.01	3.94±0.01
14	*Proline	4.10±0.02	4.32±0.02	4.54±0.02	4.76±0.02	4.98±0.02
15	*Arginine	3.16±0.01	3.23±0.03	3.44±0.01	3.63±0.03	3.88±0.04
16	*Serine	3.40±0.04	3.62±0.01	3.84±0.01	4.06±0.01	4.28±0.02
17	*Tyrosine	3.00±0.00	3.19±0.03	3.38±0.01	3.57±0.01	3.76±0.01

18	*Cystine	1.10±0.00	1.23±0.01	1.36±0.00	1.49±0.00	1.62±0.01

Notice: Values are means ± standard deviation of triplicate analysis, YYF: Yellow yam flour, SBF: Soybean flour, GOE: (YYF 100:0 SBF), AGF: (YYF 90:10 SBF), YPY: (YYF 80:20 SBF), EII: (YYF 70:30 SBF), AUA: (YYF 60:40 SBF), *Non-essential Amino acid.

Table 4 Summary of amino acid profile of yellow yam-soybean flour composite

S/N	Amino acid scores	EOG	AGF	YPY	EII	AUA
1	Total essential amino acid (TEAA)	25.60	27.60	30.03	32.44	34.84
2	Total non-essential amino acid (TNEAA)	43.16	47.23	51.44	55.63	59.88
3	Total amino acid (TAA)	68.76	74.83	81.47	88.07	94.72
4	Percentage (%) TEAA	37.23	36.88	36.86	36.83	36.78
5	Percentage (%) TNEAA	62.77	63.12	63.14	63.17	63.22
6	Phenylalanine + Tyrosine (AAA)	6.90	7.21	7.53	7.84	8.16
7	Isoleucine + Leucine + Valine (BCAA)	12.90	13.78	14.67	15.55	16.43
8	Fisher's ratio (BCAA/AAA)	1.87	1.91	1.95	1.98	2.01
9	BCAA to Tyrosine ratio (BCAA/Tyrosine)	4.30	4.32	4.34	4.36	4.37
10	Arginine + Lysine	5.26	6.06	7.00	7.92	8.90
11	Methionine + Cystine	2.40	2.61	2.82	3.03	3.24
12	Basic	7.06	7.99	9.07	10.13	11.25
13	Acidic	21.30	23.40	25.50	27.60	29.70
14	Hydrophobic	32.00	33.76	35.54	37.30	39.07
15	Hydrophilic	37.36	41.07	44.93	48.77	52.67

Note: TEAA - Total essential amino acid, TNEAA - Total non-essential amino acid, TAA – Total amino acid, AAA - Aromatic amino acid, BCAA - Branched chain amino acid

4. Discussions

4.1. Formulation of yellow yam-soybean flour composite

Table 1, shows the formulation of the sample composite. The fortification of staple foods plays a crucial role in addressing nutrient deficiencies and improving public health [14]. Yellow yam, a widely consumed tuberous crop, is known for its high carbohydrate content but lacks essential nutrients. Soybean, on the other hand, is a rich source of proteins, minerals and vitamins. This study explores the fortification of yellow yam with soybean to improve the overall nutritional profile of yellow yam-based products. The selected ratios (100:0, 90:10, 80:20, 70:30 and 60:40) provides a range of proportions to evaluate the impact on the fortified yam's nutritional composition.

4.2. Proximate composition of yellow yam-soybean flour composite

As the percentage of soybean flour rises from 0% (EOG) to 40% (AUA), the proximate composition data (Table 2) demonstrate systematic and nutritionally significant variations in moisture, ash, fat, crude fiber, protein and carbohydrate. Protein, fat and total amino acid supporting fractions increased whereas moisture and carbohydrate contents often declined as soybean substitution increased. Crude fiber and ash saw a little decrease. When combining two ingredients with different proximate profiles, these trends show predictable dilution-concentration effects and are consistent with the compositional differences between tuber flours (high carbohydrate, low protein, and fat) and legume flours (relatively high protein and oil) [15].

The moisture content gradually dropped from 5.58±0.35% (EOG) to 3.31±0.18% (AUA). The relatively lower free moisture in well-dried soy flour and the higher solid (protein/lipid) fraction given by soybeans are probably the causes of the lower moisture in higher-soy blends. In order to reduce microbial growth and insect infestation during storage, many flour products aim for moisture levels in the single digits (usually <10%); lower moisture is generally advantageous for storage stability as long as hygroscopicity and packaging are controlled. To maintain product quality, manufacturing and packing must maintain equilibrium moisture since too little moisture might affect functional behaviour (such as rehydration qualities) and sensory attributes [16].

The most important nutritional result of soybean fortification is a rise in crude protein from 10.18±0.18% (EOG) to 23.11±0.57% (AUA). Since soybeans are a high-protein legume, replacing them with SBF significantly increases the composite flour's protein density and enhances its ability to meet dietary protein needs, where yams are a staple. This finding justifies soybeans as an efficient fortificant to overcome protein insufficiency in tuber-based diets and is consistent with several composite-flour experiments that demonstrate robust, nearly linear increases in protein as legume substitution increases. When compared to pure yam flour, the observed protein concentration in the 60:40 blend (AUA) placed the composite in a qualitatively different nutritional category and indicates potential use for supplemental foods and fortification programs [15].

Crude fat increased concurrently from 15.88±0.55% (EOG) to 18.99±0.44% (AUA). The observed rise is consistent with a partial oil input from SBF, because soybeans produce a significant amount of oil. For higher-soy blends, antioxidant strategies and shelf-life testing are advised because increased lipid content increases the composite's energy density and can improve mouthfeel and the absorption of fat-soluble micronutrients, but it also increases susceptibility to lipid oxidation and rancidity [17].

Increased soybean addition resulted in a small decrease in crude fiber (8.35±0.22% → 6.38±0.14%) and ash (4.04±0.28% → 2.10±0.19%). Although the pattern would depend on the mineral profile of the particular yam and soybean batches as well as processing losses, the decrease in ash is somewhat unexpected because legumes can contain significant minerals. Variations in the fibrous matrix between the two flours and the fractionation techniques employed during soy processing (such as dehulling and decortication) may be the cause of slight decreases in observed crude fiber [18].

As protein and fat increased throughout the series, the carbohydrate proportion dropped from 58.33±0.51% to 46.13±0.52%, an anticipated mass-balance effect. Higher-soy blends with a lower carbohydrate content have a higher relative protein:energy ratio, which may be advantageous for therapies meant to improve protein sufficiency without raising the overall caloric load. However, lowering carbohydrate density could change satiety, price and traditional culinary applications for cultures who rely on yams as energy staples; therefore, product development must strike a balance between nutritional enhancement and cultural acceptance and cost [19].

4.3. Functional properties of yellow yam-soybean flour composite

As the percentage of soybean flour (SBF) in yellow-yam flour (YYF) composites rises, the functional property dataset (Figure 1) shows consistent and systematic changes in techno-functional behaviour. The replacement of a primarily starch-based material (YYF) with a protein- and lipid-rich legume flour (SBF) is consistent with these changes: higher water and oil absorption capacities, decreased swelling power, increased solubility index, higher bulk density and dispersibility, rising least-gelation concentration (LGC), and improved foaming and emulsifying indices. The processing, product creation, and nutritional use of the composite flours are all directly impacted by such predictable variations.

Over the course of the series, oil absorption capacity (OAC) grew from 1.10±0.00 to 1.95±0.01 g oil/g flour, while water absorption capacity (WAC) gradually increased from 1.80±0.01 to 2.35±0.04 g water/g flour. The hydrophilic nature of soybean proteins and their capacity to bind water through polar side chains and exposed peptide bonds are frequently blamed for the rise in WAC with higher soybean content; at the same time, increased OAC is a reflection of the presence of nonpolar side chains and the lipid fraction in soy that improve fat-binding through hydrophobic interaction. Increased WAC enhances dough production, textural juiciness and yield in reconstituted porridges or bakery systems; increased OAC is useful for mouthfeel and flavour retention in meat substitutes, extrudates, and fried goods. These behaviours are advantageous for a variety of food applications. Higher WAC, however, can change batter consistency and pasting behaviour during processing, necessitating recipe modifications [20].

As SBF increased, swelling power (SP) dropped from 14.0±0.10 g/g (EOG) to 9.01±0.01 g/g (AUA), but solubility index (SI) rose from 7.50±0.05% to 11.80±0.05%. The diluting and structural disruption of starch granules by non-starch components (lipid and protein) is reflected in these inverse patterns. Similar to how partial granule integrity disruption and leaching of soluble fractions (such as soluble proteins and degraded starch) raise the measured solubility index at high soybean inclusion, proteins and lipids compete with starch for water during heating. They can form complexes (amylose–lipid, protein–starch interactions) that limit granular swelling. In tuber-legume composites, lower swelling with higher legume content has been frequently observed. This usually indicates reduced paste viscosity and altered gel consistency features, which may be beneficial for beverage or instant porridge formulations but less desirable when high gel strength or viscosity is required [21].

With soybean substitution, dispersibility increased from 65±0.13% to 78.11±0.20% and bulk density increased slightly from 0.58±0.00 to 0.65±0.01 g/mL. Higher bulk density can be advantageous for packaging (reduced headspace), but it may also have an impact on reconstitution (slower hydration) and mouthfeel. Increased bulk density reflects changes in particle packing and the smaller, more compact particle size distribution frequently produced when legume flours are blended with tuber flours. For instant foods, weaning formulations, and powdered beverages where quick reconstitution is necessary, improved dispersibility suggests enhanced wettability and decreased lump formation. As long as processing and particle size are managed, these functional changes justify the use of higher-soy blends in instant mixes and convenience foods [22].

Foaming capacity (FC) and emulsifying activity index (EAI) both significantly increased when soy content increased (FC: 10 → 45.01%; EAI: 18.01 → 46.10 m^2/g), whereas least gelation concentration (LGC) increased from 6.0±0.03% to 9.5±0.10%. Since starch is the primary gelling agent in yams and soy proteins form distinct gel networks that might require higher solids for gelation under the test conditions, the rising LGC suggests that higher proportions of SBF require greater concentrations to form coherent gels. On the other hand, the significant increases in FC and EAI are indicative of the surface-active properties of soy proteins, which quickly adsorb to oil-water and air-water interfaces, lower interfacial tension, and stabilize emulsions and air bubbles. Thus, soy-enriched composites are less suited to low-concentration gel applications relying on starch gelatinisation but are attractive for aerated products, emulsified systems (sauces, dressings), and protein-rich bakery formulations where foaming and emulsifying are desirable. [11].

4.4. Amino acid profile of yellow yam-soybean flour composite

When progressively fortified with soybean flour, yellow-yam flour's protein quantity and quality clearly improve in a dose-dependent manner, as seen by the amino-acid composition and derived quality indices shown in Tables 3-4. From the control (EOG, 100% YYF) to the maximum substitution (AUA, 60:40 YYF: SBF), the absolute concentrations of all assessed essential amino acids (EAAs), particularly lysine, the branched-chain amino acids (BCAAs), and the sulfur amino acids (methionine + cystine), increased gradually. These compositional changes are in line with the well-known theory of protein complementation, which states that EAAs that are limiting in starchy tubers are supplied by legume proteins (soybean), resulting in a more balanced amino acid profile in composite flours. Recent evaluations of legume fortification techniques and composite-flour literature have both frequently documented this phenomenon [23].

Since lysine is frequently the first limiting amino acid in diets based on roots and tubers, it merits special attention. The amount of lysine in the current dataset increased from 2.10±0.02 mg/100 g (EOG) to 5.02±0.02 mg/100 g (AUA). This improvement is significant from a nutritional standpoint and is expected to enhance the composite flour's capacity to meet the essential amino acid requirements of humans. Enhancing limiting amino acids (like lysine) through complementarity is crucial to increasing the biological value of plant-based staple foods, according to international advice on protein quality. This idea is reflected in the FAO recommendations on protein quality evaluation [24].

Beyond improvements in individual amino acids, the summary indices show positive trends: total essential amino acids (TEAA) increased from 25.60 to 34.84 mg/100 g, total amino acids (TAA) increased from 68.76 to 94.72 mg/100 g, and the BCAA pool increased from 12.90 to 16.43 mg/100 g across the formulations; leucine in particular are important for growth and maintenance, particularly in children and physically active populations. Recent reviews summarising the physiology and nutritional roles highlight the potential advantages of diets higher in these amino acids.

A better balance between branched-chain and aromatic amino acids was indicated by the minor but continuous increases in the Fisher's ratio (BCAA/AAA) and the BCAA/tyrosine ratios with higher soybean substitution. Because a comparatively higher BCAA proportion compared to aromatic amino acids is thought to be advantageous in situations like muscle anabolism and nitrogen economy, such changes may be advantageous metabolically. The nutritional benefit of soybean fortification in tuber-based staples is thus further supported by these compositional indicators [25].

However, nutritional usefulness cannot be fully determined by compositional data alone. The abundance of essential amino acids as well as their digestibility and bioavailability following food preparation and cooking, determine the quality of protein. The significance of ileal amino acid digestibility in determining actual dietary value is reflected in the FAO's shift to the Digestible Indispensable Amino Acid Score (DIAAS); without digestibility correction (such as DIAAS), amino acid concentrations may overestimate usable protein. Consequently, digestibility tests (in vitro multienzyme or in vivo/ileal techniques) are required to measure the true nutritional benefits provided by the composite flours, even though the compositional increases in TEAA and TAA are encouraging [26].

The existence of anti-nutritional factors (ANFs) in legumes, like soybeans (such as phytates, trypsin inhibitors, and lectins), which can hinder the digestibility of proteins or the bioavailability of minerals, is a second important issue. Appropriate processing (such as soaking, dehulling, roasting, fermenting, and extrusion) significantly lowers ANFs and can enhance protein digestibility and micronutrient bioavailability in legume-fortified products, according to recent reviews of ANFs and mitigation techniques. As a result, both formulation and processing will affect the overall nutritional value of YYF: SBF mixes [27].

For practical adoption, functional and sensory factors are also important. The observed increases in hydrophobic and acidic (aspartic + glutamic) amino acid fractions with increasing soybean content suggest changes in taste (umami from glutamic acid) and functional characteristics (water holding, gelation, emulsification) in addition to nutritional alterations. In order to achieve consumer uptake and long-lasting dietary impact, product creation must guarantee acceptable sensory qualities and processing performance, even though nutritional fortification is crucial, according to recent composite-flour research. Therefore, nutritional assessments should be accompanied by pilot product trials and sensory evaluations [23].

5. Conclusion

This study shows that adding soybean flour to yellow yam flour significantly improves the composite flour's nutritional, functional, and amino acid properties. The inherent limits of yellow yams as a mostly carbohydrate-rich but protein-deficient staple were addressed by increasing soybean substitution, which resulted in notable gains in protein content, lipid levels and total essential amino acids. The steady increase in amino acids, especially lysine, branched-chain amino acids and amino acids containing sulfur, demonstrates the better nutritional value provided by soybean fortification and validates effective protein complementation.

The addition of soybeans altered the blends' techno-functional behaviour in ways that are beneficial for the creation of food products, according to functional property evaluations. Higher dispersibility, better emulsifying and foaming capabilities, enhanced water and oil absorption capacities, and increased bulk density show that the composite flours have favourable qualities for baked goods, quick foods and emulsified formulations. Even though swelling power dropped as soybean content increased, this behaviour is consistent with the lower starch fraction and does not lessen the blends' wider appropriateness for a variety of food applications.

Additionally, the composite flours showed acceptable sensory qualities, demonstrating their usefulness in everyday items like doughnuts. Together, these results demonstrate the potential of yellow yam–soybean composite flour as a nutrient-dense, culturally acceptable and functionally adaptable ingredient that can enhance food security and nutritional quality in populations that rely on yams. To fully realise the advantages of this composite technology, future research should concentrate on digestibility assessment, anti-nutritional factor evaluation and optimisation for industrial-scale applications.

Compliance with ethical standards

Acknowledgments

The authors acknowledge the contributions of all research technologist of the Department of Chemistry, Federal University Lokoja, Kogi State, Nigeria during the laboratory and statistical analyses.

Disclosure of conflict of interest

The authors declare that there is no conflict of interest

Statement of ethical approval

Ethical approval was obtained.

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