integrity Research Journals

Research Journal of Food Science and Nutrition
Volume 11(2), pages 39-48, April 2026
Article Number: 0B5E3D754
ISSN: 2536-7080
https://doi.org/10.31248/RJFSN2026.227
https://integrityresjournals.org/journal/RJFSN

Full Length Research

Effects of processing methods on the chemical, anti-nutritional factors and functional properties of African yam bean (*Sphenostylis stenocarpa*) flour

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Received Date: 18 February 2026 | Accepted Date: 30 March 2026 | Published Date: 30 April 2026

ABSTRACT: The study assessed the effects of processing methods on the chemical, anti-nutritional factors and functional properties of African yam bean flour. The study was conducted at Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. African yam bean seeds were processed into flour using different methods: cracked and boiled for 60 minutes; sprouted for 72 hours; toasted at 170℃ for 30 minutes; soaked for 12 hours and boiled for 30 minutes. Unprocessed African yam bean flour was used as the control. The chemical, anti-nutritional factors and functional properties of African yam bean flour were evaluated using standard methods of analysis. The results of the chemical composition of the flours revealed that the unprocessed African yam bean flour (UAF) had the highest contents of moisture, fat, crude fibre and amylopectin. Sprouted African yam bean flour (SAF) had the highest contents of ash and crude protein. The soaked and boiled African yam bean flour (SBF) had the highest content of carbohydrate and amylose. The results of anti-nutritional factors showed that there was a significant reduction in the oxalate, alkaloid, phytate and tannin contents of the processed African yam bean flour samples. The results of functional properties of the flour samples revealed that the bulk density, water absorption capacity and oil absorption capacity increased with processing, while the dispersibility reduced with processing. The study revealed that cracking and soaking prior to boiling were more effective in reducing the anti-nutritional factors and improved the ash, crude protein, fibre, amylose and the functional properties of the flour. African yam bean seeds should be subjected to different durations of soaking, boiling and sprouting to assess the best duration for improved nutrient content.

Keywords: African yam bean, chemical composition, flour, food processing.

INTRODUCTION

African yam bean is a leguminous crop belonging to the family *Fabaceae* and genus *Sphenostylis* (Olaniyi *et al*., 2019). The legume is grown in the tropics for its seeds and tubers. It has several local names such as “odudu”, “akidi”, “ijiriji” “uzoaki” and “azama” in the Southeastern part of Nigeria (Nnamani *et al*., 2017). African yam bean is an underutilised legume with nutritional potential that could improve protein deficiency in human nutrition due to its high nutritional values (Nnamani *et al*., 2017). Omeire (2012) reported that the amino acid composition of African yam bean is higher than that of pigeon pea, cowpea and bambara groundnut but similar to that of soybean. However, utilisation and consumption of African yam bean is low compared to other common legumes.

The under-utilisation of African yam bean is partly due to its hard-to-cook nature. Processing African yam bean for consumption requires a long cooking time and high energy cost (Adewale and Nnamani 2022). Thus, people prefer using legumes that can be processed within a limited time and with less energy. The presence of anti-nutritional factors in African yam bean is another factor that affects its utilisation (Okoye *et al*., 2024). Antinutrients are compounds present in legumes which affect their nutritional quality and efficient utilisation (Popova and Mihaylova 2019). Mosisa (2017) noted that high levels of anti-nutrients such as tannins, phytate and oxalate reduce the availability and digestibility of proteins and interfere with the absorption of amino acids. Antinutrients such as tannin, which is mostly present in the seed coat, can contribute to a 7-10% reductions in protein digestibility and reduce iron and zinc absorption (Giuberti *et al*., 2019). The various factors limiting the utilisation of African yam bean seeds could be minimised by processing (Okoye *et al*., 2024).

Food processing is the transformation of food items from the state in which they are harvested to a consumable form (Weaver *et al*., 2014). Food processing improves the quality and safety of food products for human consumption, increases shelf-life and ensures the availability of a variety of food products in and out of season (Michel *et al*., 2024). Food processing reduces antinutrients present in foods to a tolerable limit, thereby making the food safe for consumption (Sobuola *et al*., 2012; Popova and Mihaylova, 2019). Food processing involves mechanical, chemical and thermal methods that modify the food matrix and also affect the chemical structure and physiological accessibility of nutrients (Anih *et al*., 2025). Some of these processing techniques include dehulling, boiling or cooking, germination, roasting or toasting, fermentation, radiation, extrusion cooking, as well as various chemicals and enzymes (Arif *et al*., 2012). Sometimes more than one technique is utilised to effectively reduce the anti-nutritional factors in the legume (El-Hady and Habiba 2003). Taiwo *et al*. (1997) noted that legumes are often soaked in water prior to cooking to reduce cooking time.

Flour is a valuable raw material in the development of new food products due to its versatility. The suitability of flour for food product development is influenced partly by its chemical and functional properties (Eke-Ejiofor *et al*., 2022). The chemical composition of flours varies due to the raw materials from which the flours are obtained and the processing method employed. The chemical composition provides the nutrient constituents of a feed ingredient present in the flour and is important when considering the use of the flour as a food ingredient (Kumari and Sangeetha, 2017). The functional properties of a food material are those properties that reflect the complex interaction between the structure, molecular conformation of the food components, and the nature of the environment and the conditions in which they are determined (Chandra and Samsher, 2013). These properties are used to evaluate and predict the behaviour of the chemical components of the food material during preparation and cooking, as well as their effect on the texture, appearance and taste of the finished product (Awuchi *et al*., 2019). Therefore, the objective of this study was to determine the effects of processing methods such as cracked and boiled, sprouted, toasted, soaked and boiled on the chemical, anti-nutritional factors and functional properties of African yam bean flour.

MATERIALS AND METHODS

African yam bean seeds (cream coloured variety) were purchased from a local market (Orie-ugba) in Umuahia, Abia State. All the chemicals used were of analytical grade and were obtained from the Laboratory of the Department of Food Science and Technology, Michael Okpara University of Agriculture, Umudike, Abia State.

Processing of African yam bean flour

The method of Abioye *et al*. (2018) was modified, and four processing methods were used to obtain African yam bean flour (Figure 1). These are cracked and boiled, sprouted, toasted and soaked, and boiled.

Cracked and boiled African yam bean flour

African yam bean seeds were sorted, cracked with a Corona hand grinder, boiled over a gas cooker for one hour, allowed to cool and dehulled manually. The seeds were dried in an air oven at 60°C for 12 hours, milled with an electric blender (Silver Crest SC 1589) and sieved through a 250 μm mesh size sieve to obtain the flour.

Sprouted African yam bean flour

Sorted African yam bean seeds were soaked in cold water (1:5 w/v) for 12 hours, drained and evenly spread on a tray lined with moist cotton wool, covered with cotton wool and left for 72 hours to sprout. The sprouted seeds were dehulled manually, dried at 60 °C for 12 hours in an air oven, milled using a Silver Crest blender (SC 1589) and sieved with a 250 μm mesh size sieve to obtain the flour.

Toasted African yam bean flour

African yam bean seeds were sorted and toasted in an electric oven at 170°C for 30 minutes. The toasted seeds were cracked with a Corona hand grinder, winnowed to remove the husk/chaff, milled using a Silver Crest blender (SC 1589) and passed through a 250 μm mesh size sieve to obtain the flour.

Soaked and boiled African yam bean flour

African yam bean seeds were sorted and soaked in water (1:5 w/v) for 12 hours, after which the seeds were boiled for 30 minutes, allowed to cool and dehulled manually. The

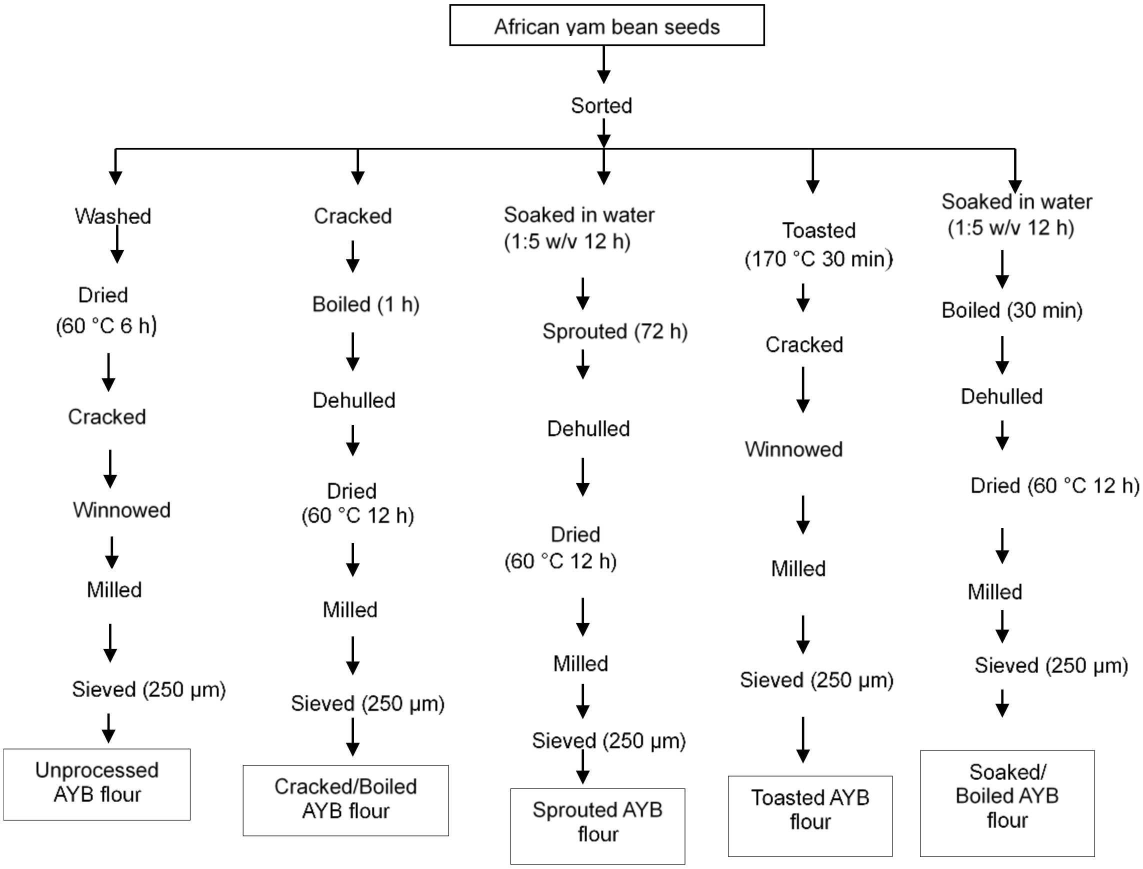

Figure 1. Processing of African yam bean flour.

dehulled seeds were dried in an air oven at 60°C for 12 hours, milled with a blender (Silver Crest blender SC 1589) and sieved using a 250 µm mesh size sieve to obtain the flour.

Unprocessed African yam bean flour

African yam bean seeds were washed in tap water, dried at 60°C for one hour in an air oven, cracked using a Corona hand grinder, winnowed to remove the chaff, milled with a Silver Crest blender (SC 1589) and sieved with a 250 µm mesh size sieve to obtain the flour.

Determination of the chemical composition of African yam bean flour

Moisture, ash, crude protein, crude fat and crude fibre contents of the African yam bean flour were determined according to the methods described by the Association of Official Analytical Chemists (AOAC, 2012).

Moisture content: Moisture content was determined using the air oven drying method. Moisture can was weighed and 2 g of the sample (2 g) was weighed into the moisture can and the weight recorded. The sample was dried in a hot air circulating oven (DHG 9140A) at 105°C for 3 hours and transferred into a desiccator to cool for an hour, and then weighed until a constant weight was obtained.

$$\%\ \text{Moisture} = \frac{\text{W3} - \text{W1}}{\text{W2} - \text{W1}}\ \text{x}\ 100$$

Where: W_1 = weight of moisture can, W_2 = weight of moisture can and sample before drying, and W_3 = weight of moisture can and sample after drying

Ash content: The sample (2 g) was weighed into a clean crucible and reweighed. The crucible with its content was placed in a muffle furnace (SXL -1002, China) chamber at 550°C for 3 hours. The crucible was removed from the furnace, cooled in desiccators and allowed to cool at room temperature and reweighed.

$$\%\ \text{Ash} = \frac{\text{W3} - \text{W1}}{\text{W2} - \text{W1}}\ \text{x}\ 100$$

Where, W_1 = weight of crucible, W_2 = weight of crucible and sample before ashing, W_3 = weight of crucible and sample after ashing.

Crude protein content: This was determined using the micro-Kjeldahl method. The sample (1 g) was weighed into a digestion flask, two tablets of Kjedahl catalyst (each containing 1 g Na_3 SO4 + 0.05 g selenium) and 25 ml sulphuric acid (H_2SO_4) were added and digested by heating at 420°C for 30 minutes in a fume cupboard. The digest was cooled, transferred into a 100 ml flask and made up to the mark with distilled water. In a 100 ml conical flask, 5 ml of boric acid indicator was added as well as 10 ml of the digest and 10 ml of 60 % sodium hydroxide (NaOH) solution. The solution was titrated against 0.01 N hydrochloric acid. A blank was also prepared without the sample. The nitrogen content was calculated, and the value was used to calculate the protein content.

$$\%\ \text{Nitrogen} = \frac{\text{VS}-\text{Vb x normality of acid x 0.014}}{\text{W}}\ \text{x}\ 100$$

$$\%\ \text{Crude protein} = \text{Nitrogen}\ \ \text{x conversion factor}\ (6.25)$$

Where: Vs = volume of acid used to titrate the sample, Vb = volume of acid used to titrate blank, W = weight of sample

Crude fat content: This was determined using the Soxhlet extraction method. The sample (2 g) was weighed and put in a thimble. The thimble was placed in a boiling flask with 100 ml of n-hexane added and allowed to reflux for 6 hours at 60 °C. The extract was dried in a hot-air oven at 100°C for 30 minutes for the solvent to evaporate and then cooled in a desiccator and weighed.

$$\%\ \text{Crude fat} = \frac{\text{W4}-\text{W3}}{\text{W2}-\text{W1}}\ \text{x100}$$

Where: W_1 = weight of thimble, W_2 = weight of thimble and sample, W_3 = weight of flask, and W_4 = weight of flask and residual oil.

Crude fibre content: The sample (2 g) was weighed, extracted with n-hexane and transferred into a flask containing 100ml of 1.25 % of sulphuric acid (H_2SO_4), placed on a heating mantle and boiled for 30 minutes. The content was filtered; the residue was washed with distilled water and transferred to a beaker containing 1.25 % of sodium hydroxide (NaOH) and boiled for 30 minutes. The content was filtered again, washed with distilled water, and the residue dried in a hot air oven at 130°C for 30 minutes, cooled in the desiccator, weighed and incinerated at 550°C for 3 hours, then cooled and reweighed.

$$\%\ \text{Crude fibre} = \frac{\text{W2}-\text{W3}}{\text{W2}-\text{W1}}\ \text{x}\ 100$$

Where: W_1 = weight of sample, W_2 = weight of sample and dish after drying, and W_3 = weight of sample and dish after incineration.

Carbohydrate content: The carbohydrate content was calculated by difference using the formula below:

% Carbohydrate = 100 – % (Moisture + Ash + Crude protein + crude Fat + Crude fibre)

Amylose and amylopectin content: Amylose was determined using the procedure described by Ekanayake *et al*. (2018). The sample (100 mg) was weighed into a flask, and 9 ml of 1 M sodium hydroxide (NaOH) and 1 ml of 95 % ethanol were added and kept overnight to gelatinise. Distilled water was used to wash the flask, transferred into a 100 ml volumetric flask and topped with distilled water. The solution was mixed properly, and 5 ml of the solution was put into a 100 ml volumetric flask. 1 ml of 1 N acetic acid and 2 ml of 0.2 % iodine solution were added, topped with distilled water, shaken properly and kept in the dark for 20 minutes. Blank was prepared with 5 ml of 0.09 NaOH, and their absorbances were read at 620 nm using a UV-VIS spectrophotometer (1138 PG Instruments Ltd). A standard curve of absorbance was plotted against amylose concentration, and the percentage of amylose was calculated using the standard curve. The amylopectin content was obtained using the formula below:

% Amylopectin = (100 - Amylose %)

Determination of Anti-nutritional factors of African yam bean flour

The anti-nutritional factors – oxalate, alkaloid phytate and tannin were determined as described by Nwosu (2013).

Oxalate: The samples (2 g each) were weighed, extracted thrice at 50 °C, stirred for 1hour with 20 ml of 0.3 M HCl. The extract was diluted to 100 ml with distilled water and used for total oxalate estimation by pipetting 5 ml of the extract, which was made alkaline with 1ml of 5 M ammonium hydroxide. Phenolphthalein (3 drops) was added to the extract and acetic acid was added in drops. About 1 ml of 5% CaCl (aq) was added to the mixture and allowed to stand for 2 hours, after which it was centrifuged at 3,000 rpm for 15 min. The supernatants were discarded, and the precipitates were washed three times with hot water, thoroughly mixed and centrifuged each time. In the test tube, 2 ml of 3 M H_2S0_4 was added, the precipitate dissolved in a water bath at 75 °C and then titrated with freshly prepared 0.01M $KMnO_4$ at room temperature until the first pink colour appeared throughout the solution, and titration continued until the pink colour persisted.

$$\%\ \text{Oxalate} = \frac{\text{Vt}}{\text{Ws x Vme x Titre}}\ \text{x}\ 100$$

Where: Vt = Total volume of Titre = 100 ml, Ws = Weight of sample, and Vme = Volume – mass equivalent (i.e.1cm^3 of 0.05M $KMnO_4$ is equivalent to 0.00225g anhydrous oxalic acid).

Alkaloid: The sample (5 g) was weighed and dispersed in

100 ml of 10% acetic acid solution in ethanol. The mixture was shaken properly, allowed to stand for 4 hours at room temperature, and filtered through Whatman No 42 grade of filter paper. The filtrate was evaporated to a quarter of its original volume; concentrated NH_3OH was added dropwise to precipitate the alkaloid, and the precipitate was filtered and dried in the oven at 60°C for 30 minutes and reweighed after cooling in a desiccator.

$$\% \text{ Alkaloid} = \frac{\text{W2} - \text{W1}}{\text{W}} \text{X100}$$

W = weight of sample, W1 =weight of empty filter paper, and W2 = weight of paper plus precipitate

Phytate: The sample (2 g) was weighed into a test tube; 10 ml of distilled water was added, and the sample was extracted using 2 ml of 0.2 M HCl (aq). About 0.5 ml of the extract was pipetted into a test tube fitted with a glass stopper, and 1 ml of ferric solution was added, covered with a stopper and heated in a boiling water bath for 30 min. The tube remained covered with the stopper for the first 15 minutes; then the test tube was cooled in ice water for 15 minutes and allowed to adjust to room temperature. The content of the test tube was mixed very well and centrifuged at 3,000 rpm for 30 min. About 1ml of the supernatant was transferred into another test tube, and about 1.5ml of 2,2 bipyridine solution was added, and the absorbance was measured at 420 nm against distilled water.

$$\% \text{ Phytate} = \frac{\text{Au}}{\text{As}} \text{ X C x } \frac{100}{\text{w}} \text{ x } \frac{\text{Vf}}{\text{Va}}$$

Au = absorbance of sample, As = absorbance of standard solution, C = concentration of standard solution, W = weight of sample, Vf = total volume of extract, Va = volume of extract analysed.

Tannin: The sample (5 g) was put inside a volumetric flask, and 50 ml of distilled water was added. The mixture was shaken for 30 minutes at room temperature and filtered to obtain the extract. A standard tannic acid solution was prepared; 2 ml of the standard solution and an equal volume of distilled water were dispersed into separate 50 ml volumetric flasks to serve as a standard and a reagent blank, respectively. Then 2 ml of the sample was put in a flask, mixed with 35 ml of distilled water, and 1ml of the Folin Denis reagent was added, followed by 2.5ml of saturated Na_2CO_3 solution. The mixture was diluted to the 50 ml mark with distilled water and incubated for 90 minutes at room temperature. The absorbance of the sample and blank was measured at 250 nm in a spectrophotometer.

$$\% \text{ Tannin} = \frac{\text{Au}}{\text{As}} \text{ X C x } \frac{100}{\text{w}} \text{ x } \frac{\text{Vf}}{\text{Va}}$$

Au = absorbance of sample, As = absorbance of standard solution, C = concentration of standard solution, W = weight of sample, Vf = total volume of extract, and Va = volume of extract analysed.

Determination of functional properties of African yam bean flour

The bulk density, water and oil absorption capacities and dispersibility of the flour samples were determined by the methods of Onwuka (2018).

Bulk density: A graduated 10 ml measuring cylinder was weighed; the cylinder was filled with the sample, and the bottom was tapped gently on the laboratory bench several times until there was no further diminution of the sample at the 10 ml mark.

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

Water and oil absorption capacities: The sample (1 g) was weighed into a graduated centrifuge tube. A waring whirl mixer was used to mix thoroughly for 30 seconds after adding 10 ml of distilled water or oil. The mixture was allowed to stand at room temperature for 30 minutes and then centrifuged at 5000 rpm for 30 minutes. The volume of free water or oil (the supernatant) was read directly from the graduated centrifuge tube.

$$\begin{aligned}&\text{Water or oil absorption capaciy}\\&= \text{ Volume of water or oil absorbed x density of water or oil}\end{aligned}$$

Dispersibility: The sample (10 g) was weighed into a 150 ml measuring cylinder, and 100 ml of distilled water was added, stirred vigorously and allowed to settle for 3 hours. The volume of settled particles was recorded and subtracted from 100 to give a difference that is taken as percentage dispersibility.

$$\text{Dispersibility } (\%\text{l}) = 100 - \text{Volume of settled pticles}$$

Statistical analysis

Data were analysed using a one-way analysis of variance (ANOVA) with Statistical Package for Social Science (SPSS) version 26.0 software, 2019. The Duncan Multiple Range Test was used to separate means where significant differences existed. Significance level was accepted at $P < 0.05$.

RESULTS AND DISCUSSION

Chemical composition of African yam bean flour

The chemical composition of African yam bean flour presented in Table 1 showed that the moisture contents of

Table 1. Chemical composition of African Yam Bean Flour (%).

Parameters (%)	Treatments				
	UAF	CBF	SAF	TAF	SBF
Moisture	9.92^{a} ±0.82	9.38^{a} ±0.08	8.74^{a} ±0.74	8.49^{a}±0.01	7.69^{a}±0.06
Ash	3.23^{a} ±0.03	1.50^{c}±0.07	3.17^{a}±0.07	3.30^{a}±0.00	1.78^{b}±0.04
Crude protein	17.79^{b} ±0.61	19.83^{ab}±0.30	21.44^{a}±0.84	20.83^{ab}±0.00	18.78^{ab}±0.61
Fat	3.78^{a}±0.26	1.79^{c}±0.01	2.19^{bc}±0.28	2.58^{b}±0.27	1.24^{d}±0.08
Crude fibre	4.78^{a} ±0.01	3.68^{ab}±1.26	1.49^{c}±0.13	3.62^{ab}±0.24	2.80^{bc}±0.56
Carbohydrate	60.48^{b}±0.26	63.81^{ab}±1.12	62.96^{ab} ±0.25	61.18^{ab}±0.03	67.72^{a}±0.16
Amylose	21.08^{e} ±0.38	23.23^{d}±0.05	24.42^{c}±0.08	27.54^{b}±0.16	28.61^{a}±0.38
Amylopectin	78.91^{a}±0.38	76.77^{b}±0.05	75.58^{c}±0.08	72.46^{d}±0.16	71.38^{e}±0.38

Values are means of three replications ± standard deviations. Means with the same superscript on the same row are not significantly different (p>0.05). Key: UAF = Unprocessed African yam bean flour (Control), CBF = Cracked and Boiled African yam bean flour, SAF = Sprouted African yam bean flour, TAF = Toasted African yam bean flour, SBF = Soaked and boiled African yam bean flour.

the samples were not significantly (p>0.05) different and ranged from 7.69% in soaked-boiled African yam bean flour (SBF) to 9.92% in unprocessed African yam bean flour (UAF). The findings agree with those of Eke-Ejiofor *et al*. (2014), who reported that different processing methods had no significant effect on the moisture content of jackfruit seed flour. The moisture content of the African yam bean flour samples was less than the maximum limit of 14.5 % for long-term storage of flour (Bodor *et al*., 2024).

Ash is the inorganic constituent of food materials and an indication of the mineral content of the samples. The ash content of the flour samples varied significantly (p<0.05) and ranged from 1.50% in cracked boiled African yam bean flour (CBF) to 3.30% in toasted African yam bean flour (TAF). The cracked and boiled African yam bean flour (CBF) and the soaked and boiled African yam bean flour (SBF) samples had the lowest ash contents, 1.50% and 1.78%, respectively. This could be attributed to the leaching of the soluble compounds during soaking and boiling. Previous studies have reported a significant reduction in ash content of soaked and dehulled cowpea (Yewande and Thomas, 2015) and processed ox-eyed bean flour (Nwajagu *et al*., 2021).

There was a significant difference (p<0.05) in the crude protein content of the African yam bean flour samples, which ranged from 17.79% in sample UAF to 21.44 % in sample SAF. The processed flour samples had higher crude protein (18.78 % - 21.44 %) content than the unprocessed sample (17.79 %), with the sprouted sample having the highest crude protein content of 21.44 %. Processing methods such as sprouting could result in an increase in protein content due to enzymatic hydrolysis that occurs during the process, which makes certain nutrients more available. The findings of the study corroborate the study of Tura *et al*. (2023), who reported an increase in protein content of germinated mung beans.

The fat content of the flour samples differed significantly, with processed flour samples having lower fat content than the control (UAF). The fat content of the flour reduced from 3.78% in sample UAF to 1.24% in sample SBF. The processed flour samples are less likely to undergo rancidity due to their lower fat content. The findings agree with Ihemeje *et al*. (2018) and Bala and Rano (2022), who reported a reduction in fat content of processed African yam bean flour and Bambara groundnut, respectively. The toasted flour sample had higher fat content (2.58%) compared to other processed flour samples. This could be attributed to the high temperature of toasting, which made the oils more available. Chauhan *et al* (2022) reported an increase of 7.51 % in the fat content of roasted soybeans. Similar findings were reported by Oboh *et al* (2010) for roasted maize, which they attributed to high temperature resulting in the effective mobilisation of the oil content in maize after the roasting process.

The fibre content of the flour samples varied significantly (p<0.05) and reduced from 4.78% in the control (UAF) to 1.49% in sample SAF (spouted AYB flour). Different processing methods have varying effects on the total dietary fibre and fibre fractions (insoluble fibre, soluble fibre) of cereals and legumes (Azizah and Zainon 1997). The reduction in fibre content of the processed samples could be due to dehulling during processing, which may have removed a considerable amount of the fibre in the flours. The findings of this study corroborate the study of Bala and Rano (2022), who reported a significant reduction in the fibre content of soaked, steamed, roasted and boiled Bambara groundnut. Anya and Ozung (2019) reported a reduction in fibre content of boiled and toasted African yam bean seeds.

The carbohydrate content of the processed samples differed significantly (p<0.05) from the unprocessed sample (UAF) (control) and was higher in all the processed samples, with the soaked and boiled African yam bean flour (SBF) having the highest (67.72%) content. The increase in the values for carbohydrate content of the processed samples could be due to the reduction in moisture, ash, fat and fibre contents of the processed samples, as carbohydrate was calculated by difference. El-Gohery (2021), reported an increase in carbohydrate content of lima bean from 60.78% (raw) to 62.63% and

Table 2. Anti-nutritional factors of African Yam Bean flour.

Samples	Oxalate (%)	Alkaloid (%)	Phytate (%)	Tannin (%)
UAF	0.37^{a} ±0.01	8.28^{a} ±0.12	0.55^{a}±0.41	0.52^{a} ±0.01
CBF	0.16 ^{b}±0.05	4.55^{b} ±1.48	0.45^{b}±0.53	0.17^{b}±0.02
SAF	0.27^{ab} ±0.01	8.20^{a}±0.56	0.47^{ab}±0.12	0.27^{ab}±0.19
TAF	0.23^{ab}±0.10	4.50^{b}±1.55	0.45^{b}±0.42	0.38^{ab}±0.04
SBF	0.28^{ab}±0.01	3.78^{b}±0.30	0.39^{b}±0.10	0.42^{ab}±0.06

Values are means ± standard deviations of duplicate determinations. Means with different superscripts in the same column are significantly different ($P < 0.05$). Key: UAF = Unprocessed African yam bean flour (Control), CBF = Cracked and Boiled African yam bean flour, SAF = Sprouted African yam bean flour, TAF = Toasted African yam bean flour, SBF = Soaked and boiled African yam bean flour.

63.89% in soaked and cooked samples, respectively. The values obtained in this study are slightly lower than the values (69.29% to 74.21%) reported by Ihemeje *et al.* (2018) for processed African yam bean.

Amylose and amylopectin are components of starch that affect the behaviour of starch when heated (Eke-Ejiofor *et al*., 2022). The amylose content of the flour samples differed significantly ($P<0.05$) and ranged from 21.08 % in the unprocessed African yam bean flour (UAF) to 28.61% in the soaked and boiled African yam bean flour (SBF). The higher amylose content of the processed flour samples suggests they would have a lower glycemic index. Flours with high amylose content have reduced gel strength due to their tightly packed structure, which makes them more resistant to digestion, thereby slowly increasing blood sugar levels (Eke-Ejiofor and Beleya, 2017). Iwe *et al*. (2016) reported 28.07 % as the amylose content of soaked African yam bean flour. Han *et al*. (2021a) noted that the molecular structure of amylose is destroyed under the action of high temperature and humidity, causing the amylose to break and form short amylose; some long amylopectin forms amylose with the transformation of its structure, which may lead to an increase in amylose content. There was a significant difference ($P<0.05$) in the amylopectin content of the flour samples, which ranged from 71.38 % in soaked boiled African yam bean flour (SBF) to 78.91 % in unprocessed African yam bean flour (UAF). Processed flour samples had a lower content of amylopectin than the unprocessed (control) sample. This implies that the processed samples would have reduced gel-forming ability and would be digested more slowly when consumed. Huynh *et al*. (2022) reported that Low amylopectin foods had a slower starch digestion rate than those with low amylose content.

Anti-nutritional factors of African yam bean flour

The anti-nutritional factors of African yam bean flour presented in Table 2 showed that the oxalate content of the African Yam bean flour samples differed significantly ($P<0.05$) and ranged from 0.16% in cracked and boiled African yam bean flour (CBF) to 0.37% in unprocessed African yam bean flour (UAF). This suggests that the processing methods had a significant effect on the oxalate content of the African yam bean flour samples. Bala and Rano (2022) also reported a reduction in oxalate content of Bambara groundnut from 4.60 mg in the raw sample to 2.20 mg in the soaked sample.

Alkaloid content of the African yam bean flour samples reduced from 8.28 % in unprocessed African yam bean flour (UAF) to 3.78% in soaked and boiled African yam bean flour (SBF). The significant reduction in alkaloid content in the soaked and boiled African yam bean flour (SBF) could be due to leaching as a result of soaking and boiling. Alkaloids are water-soluble and heat-sensitive; thus, cooking and soaking methods are more efficient than other methods in reducing alkaloid content in legumes (Haji *et al*. 2024; Abeshu and Kefale 2017). There was no significant difference between unprocessed African yam bean flour (UAF) and the sprouted African yam bean flour (SAF), suggesting that sprouting was not effective in reducing the alkaloid compared to other processing methods. This varies with the findings of Nwosu (2013), who reported a reduction in alkaloid content of malted African yam bean. Orhevba and Aloysius (2017) reported a reduction in alkaloid content from 4.00% in raw sample to 1.38% in cooked and 1.51% in soaked African breadfruit seed flours.

The phytate content of the processed African yam bean flour samples was lower and significantly different ($P<0.05$) from the unprocessed sample (UAF). Phytate is soluble in water; thus, soaking enhanced the removal of phytate from legumes (Abbas and Ahmad, 2018). The findings of this study agreed with those of Inyang *et al*. (2018), who also reported a reduction in phytate content in soaked African yam bean flour.

There was a significant difference ($p<0.05$) in the tannin content of the African yam bean flour samples, which reduced from 0.52% in the unprocessed sample to 0.17% in the cracked and boiled sample. The result implies that the processing methods were effective in reducing the tannin content of the flour samples. The values obtained in this study are within the range of 0.31 and 0.33% reported for boiled and toasted African yam bean seeds by Anya and Ozung (2019).

Table 3. Functional properties of African Yam Bean flour.

Samples	Bulk Density(g/ml)	Water Absorption Capacity (g/ml)	Oil Absorption Capacity (g/ml)	Dispersibility (%)
UAF	0.66^{bc} ±0.04	2.16^{b} ±0.06	1.91^{a} ±0.01	72.00^{a} ±0.00
CBF	0.76^{b}± 0.04	2.82^{a}±0.09	2.04^{a}±0.25	70.50^{a} ±0.70
SAF	0.68^{bc} ±0.02	2.59^{a} ±0.01	1.90^{a}±0.13	71.00^{a}±1.41
TAF	0.62^{c} ±0.00	2.35^{b}±0.07	2.10^{a}±0.01	65.00^{b}±1.41
SBF	0.86^{a}±0.04	2.81^{a}±0.01	1.97^{a} ±0.09	68.50^{ab}±0.50

Values are means ± standard deviations of duplicate determinations. Means with different superscript on the same column are significantly different ($p<0.05$). Key: UAF = Unprocessed African yam bean flour (Control), CBF = Cracked and Boiled African yam bean flour, SAF = Sprouted African yam bean flour, TAF = Toasted African yam bean flour, SBF = Soaked and boiled African yam bean flour.

Functional properties of African yam bean flour

The result of the functional properties of the African yam bean flour revealed that the bulk densities of the processed flour samples were higher than those of the unprocessed sample (UAF). The processed samples would have better thickening ability and would require more packaging material due to their higher bulk density, as presented in Table 3. The values obtained in this study are similar to the values of 0.73 g/ml reported by Henry-Unaeze and Okoye (2022) for roasted African yam bean flour and 0.89 g/ml by Olawumi *et al*. (2014) for soaked African yam bean flour.

The water absorption capacity of the flour samples increased with processing. Toasted African yam bean flour (TAF) had the least (2.35 g/ml) water absorption capacity of all the processed samples. The high fat content (2.58 %) of sample TAF may have contributed to its reduced water absorption ability. Water and oil are two liquids that cannot mix without an emulsifier; thus, flours with high amounts of oils absorb less water. The higher water absorption capacity of the processed samples suggests they are hydrophilic, would require more water and are suitable for viscose food products. Aondona *et al*. (2019) reported a reduction in water absorption capacity of soaked and boiled cowpea.

The oil absorption capacity of the flour samples did not differ significantly and ranged from 1.90 to 2.10 g/ml. The values reported in this study are higher than 0.80 ml/g reported for soaked white African yam bean flour by Olawuni *et al*. (2014). Eke-Ejiofor *et al*. (2014) reported a significant reduction in oil absorption capacity from 3.00 g/ml in raw jackfruit seed flour to 1.50 g/ml in roasted jackfruit seed flour.

There was a significant difference in the dispersibility of the flour samples, which could be due to variations in their chemical compositions and their water absorption capacities. Toasted African yam bean flour (TAF) had the least dispersibility of 65.00 % and differed significantly from the control (UAF) and other processed samples. The high fat content (2.58%) of sample TAF may have contributed to its lower (2.35 g/ml) water absorption capacity and subsequently to the lower dispersibility (Table 3). Flours with high dispersibility are easier to reconstitute, form smooth pastes and doughs and have better consistency. Adeyanju *et al*. (2021) reported similar values of 73.75% to 75.25 % for wheat/ African yam bean/acha flour blends.

Conclusion

The effect of processing methods on the chemical, anti-nutritional factors and functional properties of African yam bean (*Sphenostylis stenocarpa*) flour was studied. The findings of the study revealed that the processing methods utilised improved the chemical and functional properties and reduced the anti-nutritional factors of the African yam bean flour. The use of multiple techniques (cracked and boiled; soaked and boiled) was more effective in reducing the anti-nutritional factors of the flour without negative impact on the ash, crude protein, fibre and amylose content and the functional properties of the flour. The study suggests further studies to assess the effects of the processing methods on the mineral composition and fibre fractions of the flour. African yam bean seeds should also be subjected to different durations of soaking, boiling and sprouting to assess the best duration for improved nutrient content.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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