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Effects of thermal processing on the nutritional and antinutritional properties of African yam bean (*Sphenostylis stenocarpa*) seed flours

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ABSTRACT: The study was carried out to evaluate the effects of thermal processing treatments on nutrient and antinutrient contents of African yam bean seed flours. The African yam bean seeds were sorted, cleaned and divided into five equal lots of one kilogram each. Four lots were processed into boiled, blanched, roasted and autoclaved African yam bean flours, while the last lot was processed raw and used as control. The flour samples obtained were analysed for proximate, mineral, vitamin and antinutrient contents using standard methods. The proximate composition of the samples revealed that the flours had a range of 6.14-11.24% moisture, 8.18-14.37% crude protein, 3.06-4.61% fat, 2.04–3.32% ash, 3.18–3.56% crude fibre, 62.90–76.98% carbohydrate and 350.57–368.50 kJ/100g energy, respectively. The mineral composition of the samples showed that the flours contained 128.81–174.16 mg/100g calcium, 88.86–212.20 mg/100g, potassium, 134.71–166.77 mg/100g phosphorus, 89.17 – 122.76 mg/100g, magnesium, 14.28–18-11 mg/100g iron and 3.24–5.59 mg/100g zinc, respectively. The vitamin composition of the flours were 1.15–1.37 mg/100g ascorbic acid, 1.15–135 mg/100g thiamine, 1.19–1.55 mg/100g niacin, 1.34–1.85 mg/100g riboflavin, 1.09–1.29 mg/100g folic acid, 1.37–1.95 mg /100g vitamin A and 1.27–1.66 mg/100g vitamin E, respectively. The results showed that the roasted and autoclaved African yam bean flours generally had higher crude protein, fat, ash, crude fibre, mineral and vitamin contents than the boiled and blanched flour samples compared to the raw sample. The antinutrient composition of the flours also showed that the levels of trypsin inhibitor activity, tannin, phytate, oxalate, saponin and haemagglutinin of the samples were significantly ($p<0.05$) reduced by boiling, autoclaving roasting and blanching treatments compared to the raw sample. However, the study revealed that the processed African yam bean flours have the potentials to be used as nutrient dense ingredients in the preparation of a wide range of food products than the raw sample especially in both underdeveloped and developing countries where the problems of protein-energy malnutrition and micronutrients deficiencies are prevalent.

Keywords: African yam bean seeds, boiling, blanching, roasting, autoclaving, nutrient composition, antinutrient content.

INTRODUCTION

African yam bean (*Sphenostylis stenocarpa*), is a grain legume originated in Africa. Wild forms of this specie have been observed in all the countries along the Gulf of Guinea from Senegal to southern Nigeria (Anya, 2012). They are also found in the eastern and northern regions of Ethiopia, Eritrea, Mozambique and Tanzania (Beckley and Joseph, 2012). The African yam bean is a perennial herbaceous plant that is treated mostly as an annual crop and is used for both its seeds and tubers. Africa yam bean which is also called *Uzaki* or *Ijiriji*, among the Igbos in south-eastern Nigeria, is a bean-shaped leguminous crop that is usually black, brown, white, grey or speckled in appearance (Asoiro and Ani, 2011). It is an important source of plant protein and is equally rich in antioxidants, vitamins, minerals, and plant sterols. According to Gbenga-Fabusiwa (2021), African yam beans have many nutritional benefits which could improve the level of malnutrition, boost food security and serve as a good functional food when used in the formulation of composite flour. African yam bean is moderately rich in B-complex vitamins, especially vitamin B_6 (pyridoxine), thiamine (vitamin B_1), pantothenic acid, riboflavin and niacin. Most of these vitamins function as co-enzymes in carbohydrate, protein, and fat metabolism in the body. African yam bean is also one of the good sources of minerals like molybdenum, iron, copper, manganese, calcium and magnesium. African yam bean seeds are relatively rich in potassium which is an important electrolyte component of the cell and body fluids. It also helps to counter the pressing effects of sodium on heart and blood pressure. They can be toasted and eaten with or without the seed coat. In some villages, the toasted beans are eaten with palm kernel or coconut. The seeds could be cooked like cowpea (even though it takes longer time to cook) and eaten as bean porridge or in combination with yam “jigbu” or “abacha” (tapioca). Africa yam bean is one of the lesser known legumes that is neglected in most Nigerian homes for consumption probably because of long hours of cooking (8 – 10 h), after soaking in water coupled with the tedious manual removal of the seed coat (Thomas *et al*., 2005). African yam beans like other tropical legumes contain antinutritional substances such as trypsin inhibitors, oxalates, saponins, tannins, haemoagglutinins and phytates etc which affect their utilization and impair the bioavailability and digestibility of both macro and micro-nutrients like protein, iron, calcium and zinc unless appropriate and affordable processing techniques are implemented (Alwood *et al.,* 2006). Various methods have been used to improve the food value of African yam bean by improving its processing, storage, preservation and utilization. Such methods include soaking, boiling, roasting, blanching, autoclaving, germination, fermentation and irradiation (Anya and Ozung, 2019). These simple processing techniques may affect the physicochemical properties of the seeds and hence their potential food applications. Moderate heat treatment improves the digestibility of plant proteins without developing toxic derivatives and inactivates enzymes such as proteases, lipases, amylases, lipoxygenases and other oxidative and hydrolytic enzymes in foods (Azeke *et al.,* 2005; Anya, 2012). Roasting causes physical, chemical, structural and sensorial changes in foods. Roasting promotes the development of flavour, desired colour and increases the palability of foods (Anya and Ozung, 2019). One of the main derived outcomes of roasting treatment is the increase in antioxidant activity due to the formation of Maillard reaction products (Chinma *et al.,* 2009). Boiling has the ability to destroy protease inhibitors and saponins in African yam beans. Autoclaving and boiling have been reported to enhance the taste a nd flavour of foods. They also give food longer keeping quality and decrease the anti-nutritional and toxic substances in foods (Ajayi, 2011). Blanching inactivates enzymes and destroys flatulence causing oligosaccharides in foods. However, these processing methods in some cases, rather than improving the nutritional value of foods, they adversely affect them. The objective of the study was to evaluate the effects of thermal processing on the nutrient and antinutrient contents of African yam bean flours.

MATERIALS AND METHODS

Procurement of the raw materials

Mature dried African yam bean seeds used for the study were bought from Ogbete Main Market, Enugu, Enugu State, Nigeria.

Pre-preparation of the seed samples

The seeds were procured, sorted manually to remove stones, sands, damaged and immature seeds and divided into five equal lots of 1 kg each. The first lot was processed raw, while the other four lots were subjected to different heat processing treatments (boiling, blanching, roasting and autoclaving).

Preparation of raw African yam bean flour

The raw African yam bean flour was prepared according to the method described by Anya and Ozung (2019). One kilogram (1 kg) of African yam bean seeds was cleaned with 3 litres of potable water to remove the dirt and other extraneous materials. After that, the cleaned seeds were drained, rinsed, spread on the trays and dried in a hot air oven (Model DHG 9101 ISA) at 60°C for 10 hours with occasional stirring of the seeds at intervals of 30 minutes to ensure uniform drying. The dried seeds were dehulled by cracking them in the attrition mill followed by winnowing to remove the hulls. The dehulled seeds were milled into flour using the attrition mill and sieved through a 500 micron mesh sieve. The flour produced was packaged in an airtight plastic container, labelled and kept in a refrigerator until needed for analysis.

Preparation of boiled African yam bean flour

The boiled African yam bean flour was prepared according to the method described by Anya and Ozung (2019). One kilogram (1 kg) of the cleaned seeds was soaked in 3 litres of potable water at room temperature (30±2°C) for 8 hours. The soaked seeds were drained, rinsed and dehulled manually by rubbing them in between palms to remove the hulls. The dehulled seeds were boiled with 2.5 litres of potable water at 100°C for 30 minutes on a hot plate. The boiled seeds were drained, spread on the trays and dried in a hot air oven (Model DmkHG 9101 ISA) at 60°C for 14 hours with occasional stirring of the seeds at intervals of 30 minutes to ensure uniform drying. The dried seeds were milled into flour using the attrition mill and sieved through a 500 micron mesh sieve. The flour produced was packaged in an airtight plastic container, labelled and kept in a refrigerator until needed for analysis.

Preparation of blanched African yam bean flour

The blanched African yam bean flour was prepared according to the method described by Anya and Ozung (2019). One kilogram (1 kg) of the cleaned seeds was soaked in 3 litres of potable water at room temperature (30±2°C) for 8 hours. The soaked seeds were drained, rinsed and dehulled manually by rubbing them in between palms to remove the hulls. The dehulled seeds were hot water blanched at 75°C for 15 minutes on a hot plate. The blanched seeds were drained, spread on the trays and dried in a hot air oven (Model DHG 9101 ISA) at 60°C for 12 hours with occasional stirring of the seeds at intervals of 30 minutes to ensure uniform drying. The dried seeds were milled into flour using the attrition mill and sieved through a 500 micron mesh sieve. The flour produced was packaged in an airtight plastic container, labelled and kept in a refrigerator until needed for analysis.

Preparation of roasted African yam bean flour

The roasted African yam bean flour was prepared according to the method described by Anya and Ozung (2019). One kilogram (1 kg) of the cleaned seeds was soaked in 3 litres of portable water at room temperature (30±2°C) for 8 hours. The soaked seeds were drained, rinsed and dehulled manually by rubbing them in between palms to remove the hulls. The dehulled seeds were rinsed, spread on the trays and roasted in a hot air oven (Model DHG 9101 ISA) at 240°C for 90 minutes with occasional stirring of the seeds at intervals of 10 minutes to ensure uniform roasting. The roasted seeds were milled into flour using the attrition mill and sieved through a 500 micron mesh sieve. The flour produced was packaged in an airtight plastic container, labelled and kept in a refrigerator until needed for analysis.

Preparation of autoclaved African yam bean flour

The autoclaved African yam bean flour was prepared according to the method described by Anya and Ozung (2019). One kilogram (1 kg) of the cleaned seeds was soaked in 3 litres of potable water at room temperature (30±2°C) for 8 hours. The soaked seeds were drained, rinsed and dehulled manually by rubbing them in between palms to remove the hulls. The dehulled seeds were placed in a beaker and autoclaved in an autoclave (Model 75 x G, UK, England) at a temperature of 121°C and pressure of 6 atmospheres for 1 hour. The autoclaved seeds were spread on the trays and dried in a hot air oven (Model DHG 9101 ISA) at 60°C for 8 hours with occasional stirring of the seeds at intervals of 30 minutes to ensure uniform drying. The dried seeds were milled into flour using the attrition mill and sieved through a 500 micron mesh sieve. The flour produced was packaged in an airtight plastic container, labelled and kept in a refrigerator until needed for analysis.

Proximate analysis

The moisture, crude protein, fat, ash and crude fibre contents of the samples were determined on a weight basis according to the methods of AOAC (2010). Carbohydrate was determined by difference (AOAC, 2010). The energy content of the flours was calculated from the proximate composition using the Atwater factors of 4×protein, 9×fat and 4×carbohydrate (AOAC, 2010). All determinations were carried out in triplicate samples.

Mineral analysis

The potassium content of the samples was determined on a dry weight basis using the flame photometer (Model FP 640) according to the method of AOAC (2010). The calcium content of each sample was determined according to EDTA versanate complexometric method of AOAC (2010). The magnesium, phosphorus, iron and zinc contents of the samples were determined using the atomic absorption spectrophotometer (Model 320N) according to the methods of AOAC (2010). All determinations were carried out in triplicate samples.

Vitamin analysis

The vitamin A, ascorbic acid, vitamin E and folic acid contents of the flour samples were determined on dry weight basis according to the methods of AOAC (2010). The thiamine and riboflavin contents of the flour samples were determined according to the fluorimetric methods of AOAC (2010). The niacin content of the flours was determined according to the colourimetric method of AOAC (2010). All determinations were carried out in triplicate samples.

Anti-nutrient analysis

The saponin, oxalate, trypsin inhibitor and tannin levels of the flour samples were determined on dry weight basis according to the spectrophotometric methods described by Onwuka (2005). The phytate and haemagglutinin contents were determined using the spectrophotometric methods of AOAC (2010). All determinations were carried out in triplicate samples.

Statistical analysis

The data generated were subjected to one-way analysis of variance (ANOVA) using Statistical Package for Social Sciences (SPSS, Version 23) software. Significant means were separated using Turkey's least significant difference (LSD) test at p<0.05.

RESULTS AND DISCUSSION

Proximate composition of raw and processed African yam bean flour samples

The proximate composition of raw and processed Africa yam bean flour samples are presented in Table 1. The moisture content of the raw sample was 11.24% and that of the processed samples ranged between 6.14 to 11.24% with the roasted sample having the least value (6.14%), while the boiled sample had the highest (6.56%) value. There were significant differences (p<0.05) in the moisture content of the flour samples. The increase in the moisture content of the boiled flour sample could be attributed to the absorption of the large quantity of water by the seeds as a result of boiling during processing. The observation is in agreement with the report of Nsa and Ukachukwu (2009). The moisture contents of the raw and processed samples were comparable to the values (11.85% and 6.12–6.89%) reported by Arawande and Borokin (2010) and Onuoha *et al*. (2017) for raw and boiled pigeon pea and African yam bean flours, respectively. The moisture contents of both the raw and processed samples were within the maximum range of moisture (0-13%) that is compatible with the proper packaging and storage of legume flours (Azeke *et al*., 2005). The low levels of moisture in raw, boiled, blanched, roasted and autoclaved samples of African yam bean flour suggest that they could keep for a long period without deterioration and spoilage that could be caused by the presence of microorganisms and chemical reactions. The moisture content of the food is used as a measure of its stability and susceptibility to microbial and chemical/enzymatic deterioration and spoilage during storage.

The crude protein contents of the raw sample was 14.37% and that of the processed samples ranged between 8.18 and 12.32% with the boiled and roasted samples having the least (8.18%) and the highest values (12.32%), respectively. The crude protein values (14.37% and 8.18–12.32%) obtained in this study for both the raw and processed flours were lower than the protein contents (12.18% and 6.12–10.280%) reported by Jacob *et al*. (2015) for raw, cooked and roasted melon seed flours. There were significant differences (p<0.05) in the crude protein contents of the flour samples. The crude protein content of the flour samples was significantly higher (p<0.05) in roasted and autoclaved samples compared to the samples processed by boiling and blanching treatments. The reduction in the protein contents of the boiled and blanched samples could be attributed to leaching of some soluble proteins into boiling and blanching water during processing (Obasi and Wogu, 2008; Akubor, 2017). It has been earlier reported that when food is subjected to roasting and autoclaving, the activities of the proteolytic enzymes are increased (Mbah *et al*., 2012). The higher protein values obtained for the roasted and autoclaved samples could be due to the increase in the activities of proteolytic enzymes which hydrolysed the inherent proteins to their constituent amino acids and peptides. Dietary proteins are needed for the synthesis of new cells, enzymes and hormones required for the development of the body (Okaka *et al*., 2006).

The fat contents of the raw, boiled, blanched, roasted and autoclaved samples of African yam bean flours were 4.61, 3.06, 3.10, 3.23 and 3.16%, respectively. The results showed that boiling and blanching treatments significantly (p<0.05) reduced the fat content than the roasting and autoclaving (3.32 and 3.16%) techniques compared to the raw sample which had the highest fat content (4.16%). The observed decrease in fat contents of boiled and blanched African yam bean flours could be due to oxidative breakdown of fat components into fatty acids and glycerol as a result of heat during processing. The fat content of the flour samples was generally higher compared to other alternative protein sources such as pigeon pea (2.33%), velvet bean (1.61%) and sword bean (2.94%) (Ahamefule, 2005; Akinmutimi, 2007; Elais *et al.,* 2010) but fell within the range reported for *Canavallia plagiosperma* seeds (5.94%) (Ahamefule and Odoemelam, 2008). In addition, the studies carried out by other researchers (Asoiro and Ani, 2011; Chinwendu *et al*., 2014) revealed that the fat content of African yam bean has a composition that is comparable to that of groundnut and cotton seed oil by being high in palmitic and oleic acids. However, the high fat content (3.5%) of African yam bean seeds can cause rancidity in foods prepared from the seed flours, and this could be overcome through the extraction of the oil before being used in the formulation of food products or by the addition of antioxidants. Fat is important in human diets because it is a high energy-yielding nutrient (Oraka and Okoye, 2017).

The ash content of the raw sample was 3.32% and that of the processed samples ranged from 2.04 to 2.96%. The boiled sample had the least value (2.04%), while the roasted sample had the highest value (2.96%) which was slightly lower than the ash content of the raw sample

Table 1. Proximate composition (%) of raw and processed African yam bean flour samples

Parameters	Raw	Boiled	Blanched	Roasted	Autoclaved
Moisture	$11.24^{a} \pm 0.01$	$6.56^{b} \pm 0.01$	$6.43^{c} \pm 0.16$	$6.14^{e} \pm 0.01$	$6.22^{d} \pm 0.03$
Crude Protein	$14.37^{a} \pm 0.01$	$8.18^{e} \pm 0.01$	$10.15^{d} \pm 0.01$	$12.32^{b} \pm 0.04$	$11.33^{c} \pm 0.02$
Fat	$4.61^{a} \pm 0.01$	$3.06^{e} \pm 0.01$	$3.10^{d} \pm 0.04$	$3.23^{b} \pm 0.07$	$3.16^{c} \pm 0.01$
Ash	$3.32^{a} \pm 0.01$	$2.04^{e} \pm 0.01$	$2.12^{d} \pm 0.01$	$2.96^{b} \pm 0.05$	$2.87^{c} \pm$ 0-02
Crude Fibre	$3.56^{a} \pm 0.01$	$3.18^{e} \pm 0.01$	$3.20^{d} \pm 0.01$	$3.46^{b} \pm 0.01$	$3.23^{c} \pm 0.03$
Carbohydrate	$62.90^{e} \pm 0.01$	$76.98^{a} \pm 0.06$	$75.00^{b} \pm 0.02$	$71.89^{d} \pm 0.03$	$73.19^{c} \pm 0.26$
Energy (KJ/100g)	$350.57^{e} \pm 0.08$	$368.18^{b} \pm 0.02$	$368.50^{a} \pm 0.47$	$365.91^{d} \pm 1.79$	$366.52^{c} \pm 0.23$

Values are mean ± standard deviation of triplicate determinations. Means within the same row with different superscripts are significantly different at p<0.05.

(3.32%). The result showed that the African yam bean flours were generally low in ash content and had the values that could not compare favourably with other alternative vegetable protein sources like pigeon pea, lima bean, lablab bean, *Mucuna* bean and castor oil seed flours with ash contents of 2.85, 3.22, 3.56, 4.31 and 5.61%, respectively (Carew *et al*., 2003; Ahamefule, 2005; Akinmutimi, 2007; Nsa, 2008). The ash content showed significant (p<0.05) difference between the raw and thermally processed African yam bean flour samples. The raw sample however recorded higher ash content (3.32%) compared to the boiled (2.04%) and blanched (2.12%) samples which had the least ash contents. The decrease in ash contents of the boiled and blanched flours could be attributed to leaching of some mineral elements into boiling and blanching media during processing. The observations are in close agreement with the reports of Ukachukwu and Obioha (2000) and Nsa (2008) for boiled and blanched *Mucuna Cochinchinosis* and castor oil seed flours, respectively. In this present study, autoclaving and roasting treatments recorded the highest values of 2.87% and 2.96%, respectively compared to the sample processed by boiling treatment (2.04%). This trend is also in line with the reports of Ahamefule and Odoemelam (2006) and Oraka and Okoye (2017) who stated that roasted and autoclaved flour samples had higher ash contents than the samples processed by boiling and blanching treatments. The increase in ash contents of autoclaved and roasted flour samples may be as a result of loss of moisture due to the application of dry heat, which tends to increase the concentration of inorganic contents of the flours.

The crude fibre content of the raw sample was 3.56% and that of the processed samples which ranged between 3.18 and 3.46% was significantly (p<0.05) lower in boiled and blanched flours compared to the samples processed by autoclaving (3.23%) and roasting (3.46%) treatments. The result showed that the crude fibre content of the processed flours was generally lower than that of the raw sample which recorded the highest (3.56%) value. The decrease in the crude fibre contents of boiled and blanched samples is in agreement with the findings of Onuoha *et al.* (2017) who reported that boiling and blanching generally reduced the crude fibre contents of legumes. The observed trend in this study could be due to the softening and subsequent loss of the hard coat of some of the seeds during the boiling and blanching processes. Fibre has been credited for the promotion of increased excretion of bile acids, sterols and fats which have been implicated in the etiology of certain ailments in humans (Okaka *et al.*,2006). Some of the crude fibres are hydrophilic and so, they help to maintain the moist and soft condition of faecal mass which facilitates easy passage of it through the large bowel or large intestine.

The carbohydrate content of the samples varied from 62.90% for the raw sample to 71.89% (roasted), 73.19% (autoclaved), 75.00% blanched and 76.98% (boiled), respectively. Thermal processing resulted in carbohydrate values that were significantly (p<0.05) different. Boiling and blanching of African yam bean seeds during processing significantly (p<0.05) increased the carbohydrate content compared to the roasting and autoclaving treatments which drastically decreased the carbohydrate contents of the roasted and autoclaved flour samples. The relatively low carbohydrate values recorded by the roasted and autoclaved African yam bean flours could be attributed to reduction in solubilization and breakdown of some carbohydrate components into carbonic acid and carbon dioxide by roasting and autoclaving treatments during processing (Obasi and Wogu, 2008).

The energy content of the samples varied from 350.57 kj/100g for the raw sample to 368.18, 368.50, 365.91 and 366.52 kJ/100g for the samples processed by boiling, blanching, roasting and autoclaving treatments, respectively. There were significant (p<0.05) differences in the energy contents of raw and processed flour samples. Boiling and blanching of African yam bean seeds during processing caused significant (p<0.05) increase in the energy values of the samples than the raw, roasted and autoclaved flour samples which had the energy values of 350.57, 365.91 and 366.52 KJ/100g, respectively. The lower energy values of roasted and autoclaved African yam bean flours compared to the boiled and blanched flour samples may be due reduction in their carbohydrate contents and volatility of energy related nutrients like fat during processing as a result of roasting and autoclaving treatments. The observation is in agreement with the report of Ahamefule and Odoemelam (2006) for roasted and autoclaved *Canavalis Plagiosperma* seed flours. Generally, boiling, blanching, roasting and autoclaving treatments greatly reduced the crude protein, fat, ash and crude fibre contents of the flours with slight increase in their carbohydrate and energy contents compared to the raw sample.

Mineral composition of raw and processed African yam bean four samples

The mineral composition of raw and processed African yam bean flour samples are presented in Table 2. The calcium content of the raw sample was 174.16 mg/100g and that of the processed samples ranged between 124.81 and 168.70 mg/100g with the boiled sample having the least value (124.81 mg/100g), while the roasted sample had the highest value (168.70 mg/100g). The values (124.81–174.16 mg/100g obtained in this present study were lower than the calcium contents (220.95–245.5 mg/100g) reported by Uche *et al*. (2014) for raw and processed African yam bean seed flours and those (176.89–234.72 mg/100g) reported by Oraka and Okoye (2017) for raw and processed lima bean flours respectively. There were significant differences ($p<0.05$) in the calcium content of the flour samples. The calcium content of the samples was significantly ($p<0.05$) reduced by boiling and blanching treatments compared to the samples processed by roasting and autoclaving techniques. The decrease could be due to leaching of the mineral element into boiling and blanching media during processing. Calcium in conjunction with magnesium, phosphorus and protein are involved in bone formation (Okaka *et al*., 2006). It is also important in blood clotting and muscle contraction. It is equally involved in hormonal signals, glucose metabolism, enzyme reactions, release of neurotransmitters and maintenance of membrane integrity and excitability (Ukachukwu, 2000).

The potassium content of the raw sample was 212.20 mg/100g and that of the processed flours ranged between 88.86 and 188.85 mg/100g with the boiled sample having the least value (88.86 mg/100g), while the roasted sample had the highest value (188.85 mg/100g). The potassium content values (88.86–188.85 mg/100g) obtained in this study were higher than the values (82.22–104.52 mg/100g) reported by Anya and Ozung (2019) for boiled and toasted African yam bean flours. There were significant ($p<0.05$) differences in the potassium content of the flour samples. Roasting and autoclaving treatments relatively increased the potassium content of the flour samples whereas boiling and blanching processes drastically reduced the potassium content of the flours when compared to the potassium content of the raw sample. The significant ($p<0.05$) decrease in the potassium content of the boiled sample could be attributed to the degradation and leaching of the mineral element into the boiling water during processing (Akubor, 2017). The observation is in agreement with the results obtained by Oraka and Okoye (2017) and Anya and Ozung (2019) for boiled lima bean and African yam bean flours, respectively. Potassium is essential in blood clotting and muscle contraction. It is also needed for the maintenance of proper fluid and electrolyte balance, nerve transmission, muscle contraction and cell integrity in the human body (Eze *et al.,* 2019).

The phosphorus content of the raw flour was 166.77 mg/100g and that of the processed samples ranged between 134.71 and 166.77 mg/100g with the boiled sample having the least value (134.71 mg/100g), while the autoclaved sample had the highest value (155.90 mg100g) which was significantly ($p<0.05$) lower than the phosphorus content of the raw sample (166.77 mg/100g). The values (134.71–155.90 mg/100g) obtained in this study were higher than the phosphorus content (28.07–40.53 mg/100g) reported by Uche *et al*. (2014) for boiled and roasted *Sphenostylis stenocarpa* seed flours but lower than the values (158.78–184.29 mg/100g) reported by Oraka and Okoye (2017) for boiled and roasted lima bean flours. There were significant differences ($p<0.05$) in the phosphorus content of the flour samples. The phosphorus content of the flour samples was significantly ($p<0.05$) reduced by boiling and blanching treatments compared to the samples processed by roasting and autoclaving techniques. The reduction in the phosphorus contents of the boiled and blanched samples could be due to oxidation and leaching of the mineral element into boiling and blanching media during processing. Phosphorus is one of the minerals that human beings require in greater amounts. It helps to control the acid-base balance of the body and is also required in the highest amount by young children, and pregnant and nursing mothers (Okaka *et al*., 2006).

The magnesium content of the raw was 122.76 mg/100g and that of the processed samples ranged from 89.71 to 114.44 mg/100g with the boiled sample having the least value (89.71 mg/100g), while the roasted sample had the highest value (114.44 mg/1000g) which was significantly lower than the magnesium content of the raw sample (122.76 mg/100g). The magnesium content (89.71–114.44 mg/100g) obtained in the study was higher than the values (44.22-58.26 mg/100g) reported by Uche *et al*. (2014) and Anya and Ozung (2019) for boiled and roasted African yam bean flours. There were significant differences ($p<0.05$) in the magnesium content of the flour samples. The magnesium content of the flour samples was significantly

Table 2. Mineral composition (mg/100g) of raw and processed African yam bean flour samples.

Parameters	Raw	Boiled	Blanched	Roasted	Autoclaved
Calcium	174.16^{a} ± 0.01	124.81^{e}± 0.07	154.21^{d} ± 0.61	168^{b}.70±0.17	162.89^{c} ± 0.11
Potassium	192.20^{a} ± 1.31	85.86^{e} ± 1.32	95.24^{d} ± 1.31	188.85^{b} ±1.33	172.11^{c} ± 0.07
Phosphorus	166.77^{a} ± 1.25	134.71^{e} ± 0.67	147.16^{d} ± 0.55	155.78^{c} ± 1.90	155.90^{b} ±0.66
Magnesium	122.76^{a} ± 0.58	89.71^{e} ± 0.77	95.28^{d} ±0.33	114.44^{b} ± 1.09	105.23^{c} ± 0.55
Iron	18.11^{a} ± 0.01	14.28^{e} ± 0.07	15.40^{d} ±0.38	17.35^{b} ±0.01	16.56^{c} ± 0.04
Zinc	5.59^{a} ± 0.07	3.24^{e} ± 0.38	3.46^{d}±0.05	3.88^{b} ±0.04	3.78^{c} ± 0.01

Values are mean ± Standard deviation of triplicate determinations. Means within the same row with different superscripts are significantly different at p<0.05.

(p<0.05) reduced by boiling and blanching treatments compared to the samples processed by the autoclaving and roasting techniques which relatively recorded higher values (105.23 mg/100g and 114.44 mg/100g) when compared with the raw sample which had the highest value (122.76 mg/100g). Magnesium is also an important component of bone and it contributes to the structural development of the muscles (Jacob *et al*., 2015). Its deficiency can result in uncontrolled twisting of muscles which may lead to convulsion and death (Etong *et al*., 2013).

The iron content of the raw flour sample was 18.11mg/100g and that of the processed samples ranged between 14.28 and 17.35 mg/100g with the boiled sample having the least value (14.28 mg/100g), while the roasted sample had the highest value (17.35 mg/100g) which was slightly lower than the value of the raw sample (18.11 mg/100g). There were significant differences (p<0.05) in the iron content of the flour samples. The iron content values (14.28–17.35 mg/100g) obtained in this study were higher than the values (13.10 –13.27 mg/100g), (10.11 – 11.06 mg/100g) and (12.38 – 13.24 mg/100g) reported by Ndidi *et al*. (2014), Oraka and Okoye (2017) and Anya and Ozung, (2019) for boiled and roasted African yam bean and lima bean flours, respectively. The decrease in the iron content of the boiled sample could be probably caused by the degradation and leaching of the mineral element into boiling water during processing (Akubor, 2017). The observation is in agreement with the findings of Nsa and Ukachukwu (2009) and Oraka and Okoye (2017) for boiled oil castor seed and lima bean flours, respectively. Iron is an important component of haemoglobin which is an oxygen-carrying pigment in the blood (Potter and Hotchkiss, 2006). Iron is an essential mineral in human health which plays a significant role in immune function, cardiovascular health and cognitive development (Seena *et al*., 2006).

The zinc content of the raw sample was 5.59 mg/100g and that of the processed samples ranged from 3.24 to 3.88 mg/100g with the boiled sample having the least value (3.24 mg/100g), while the roasted flour had the highest value (3.98 mg/100g) which was relatively lower than the value of the raw sample (5.59 mg/100g). There were significant differences (p<0.05) in the zinc content of the flour samples. The zinc content (3.24–3.88 mg/100g) obtained in this study was lower than the values (3.37–6.05 mg/100g) reported by Ndidi *et al*. (2014) for boiled and roasted African yam bean flours, respectively. The low zinc content of the boiled sample is in agreement with the reports of Oraka and Okoye (2017) and Anya and Ozung (2019) for boiled lima bean and African yam bean flours, respectively. Zinc has been known to promote wound healing, and it also plays a role in taste, appetite and growth (Alayande *et al*., 2012). Generally, roasting and autoclaving treatments had a greater effect on enhancing the mineral contents of African yam bean flour than boiling and blanching techniques.

Vitamin composition of raw and processed African yam bean flour samples

The vitamin contents of raw and processed African yam bean flour samples are presented in Table 3. The ascorbic acid content of the raw flour was 1.37 mg/100g and that of the processed flour samples ranged from 1.15 –1.35 mg/100g with the boiled sample having the least value (1.15 mg/100g), while the roasted sample had the highest value (1.35 mg/100g). The raw sample had the highest ascorbic acid content compared to the processed samples regardless of the heat processing treatment applied. There were significant differences (p<0.05) in the ascorbic acid content of the flour samples. The significant (p<0.05) decrease in the ascorbic content of boiled and blanched flours could be due to the leaching of the vitamin into boiling and blanching media during processing. The result is in agreement with the reports of Fadahunsi (2009), Arukwe *et al*. (2017) and Oraka and Okoye (2017) who stated that boiling and blanching treatments resulted in a remarkable decrease in ascorbic acid contents of boiled and blanched of Bambara, lima bean and pigeon pea flours, respectively. Olanipekun *et al* (2015) also reported that boiling and blanching processes equally reduced the ascorbic acid content of kidney bean flour. Ascorbic acid is

Table 3. Vitamin composition (mg/100g) of raw and processed African yam bean flour samples.

Parameters	Raw	Boiled	Blanched	Roasted	Autoclaved
Ascorbic acid	$1.37^{a} \pm 0.01$	$1.15^{e} \pm 0.01$	$1.22^{d} \pm 0.02$	$1.35^{b} \pm 0.03$	$1.26^{c} \pm 0.01$
Thiamine	$1.35^{a} \pm 0.02$	$1.15^{d} \pm 0.01$	$1.25^{c} \pm 0.01$	$1.28^{b} \pm 0.03$	$1.26^{b} \pm 0.01$
Niacin	$1.55^{a} \pm 0.01$	$1.19^{d} \pm 0.03$	$1.35^{c} \pm 0.02$	$1.40^{c} \pm 0.04$	$1.47^{b} \pm 0.13$
Riboflavin	$1.85^{a} \pm 0.02$	$1.34^{d} \pm 0.07$	$1.36^{d} \pm 0.01$	$1.44^{c} \pm 0.04$	$1.58^{b} \pm 0.71$
Folic acid	$1.29^{a} \pm 0.05$	$1.09^{d} \pm 0.04$	$1.19^{c} \pm 0.01$	$1.24^{b} \pm 0.01$	$1.27^{b} \pm 0.11$
Vitamin A	$1.95^{a} \pm 0.01$	$1.37^{e} \pm 0.04$	$1.67^{d} \pm 0.07$	$1.78^{c} \pm 0.01$	$1.86^{b} \pm 0.01$
Vitamin E	$1.66^{a} \pm 0.00$	$1.27^{d} \pm 0.06$	$1.36^{c} \pm 0.01$	$1.50^{b} \pm 0.02$	$1.53^{b} \pm 0.01$

Values are mean ± standard deviation of triplicate determinations. Means within the same row with different superscripts are significantly different at $p<0.05$.

an antioxidant which helps to scavenge free radicals in the cells. It also promotes wound healing, healthy immune system and prevents scurvy and cardiovascular diseases (Okaka *et al*., 2006). The result showed that roasting and autoclaving drastically improved the ascorbic acid content of African yam bean flour compared to boiling and blanching treatments.

The thiamine content of the raw flour was 1.35 mg/100g and that of the processed samples ranged from 1.15–1.28 mg/100g. Out of the processed samples, the boiled sample had the least value (1.15 mg/100g), while the roasted sample had the highest value (1.28 mg/100g). There were significant differences ($p<0.05$) in the thiamine contents of the boiled and blanched flour samples but the roasted and autoclaved flours showed no significant ($p>0.05$) difference. The thiamine content (1.15–1.28 mg/100g) obtained in this study was higher than the values (0.34–1.07mg/100g and 0.03–0.07 mg/100g) reported by Arukwe *et al*. (2017) and Oraka and Okoye (2017) for boiled and roasted pigeon pea and lima bean flours, respectively. The reduction in thiamine content of boiled and blanched samples could be due to degradation and leaching of the vitamin into boiling and blanching media during processing (Akubar, 2017). Thiamine functions as a co-enzyme in energy metabolism. It also helps in the proper functioning of peripheral nerves and the treatment of beriberi (Potter and Hotchkiss, 2006).

The niacin content of the processed flour samples ranged from 1.19–1.47 mg/100g and that of the raw sample was 1.55 mg/1000g. The result showed that the boiled sample had the least value 1.19 mg/100g, while the autoclaved flour sample had the highest value (1.47 mg/100g) compared to the samples processed by blanching (1.35 mg/100g) and roasting (1.40 mg/100g) treatments. The decrease in the niacin content of the boiled sample could be a result of the leaching of the vitamin into boiling water and this observation is in agreement with the report of Fadahunsi (2009) for boiled Bambara groundnut flour. Niacin plays a key role in the tricarboxylic acid cycle. It also has specific effects on the growth and reduction of the levels of blood cholesterol in the human body (Graham and Welch, 1996).

The riboflavin content of the raw sample was 1.85 mg/100g and that of the processed flour samples ranged from 1.34–1.58 mg/100g with the boiled sample having the least value (1.34 mg/100g), while the autoclaved sample had the highest value (1.58 mg/100g) which was relatively lower than the riboflavin content of the raw sample. There were significant differences ($p<0.05$) in the riboflavin content of flour samples. The result showed that the riboflavin content values (1.34–1.58 mg/100g) obtained in this study were higher than the riboflavin content (0.03–0.67 mg/100g) reported by Nwanekezi *et al*. (2017) for boiled pigeon pea flour. The decrease in the riboflavin content of the boiled and blanched samples is in agreement with the report of Uherova *et al*. (1993) who reported that conventional cooking and blanching resulted in greater loss of riboflavin in vegetables because it is highly soluble in water. It was also observed from the result that autoclaving and roasting had greater effects in enhancing the riboflavin content of African yam bean flours than the boiling and blanching treatments when compared to the raw sample which relatively had the highest riboflavin content (1.85 mg/100g). Riboflavin (Vitamin B_2) plays a critical role in the body's energy production. The presence of riboflavin in the body improves growth and reproduction and also prevents anaemia and abnormal gait (Okaka *et al*., 2006).

The folic acid content of the processed African yam bean flour samples ranged from 1.09–1.27 mg/100g and that of the raw sample was 1/.29 mg/100g. The boiled sample had the lowest value (1.09 mg/100g) followed by blanched (1.19 mg/100g), roasted (1.324 mg/100g) and autoclaved (1.27 mg/100g) samples. There were significant ($p<0.05$) differences in the folic acid contents of boiled and blanched flours, while the roasted and autoclaved flour samples showed no significant ($p>0.05$) difference. The reduction in folic acid contents of boiled and blanched flour samples compared to the other samples could be a result of the leaching of the vitamin into boiling and blanching media during processing (Akubor, 2017). Folic acid helps in the synthesis and maintenance of new cells in the body. It also helps to prevent changes in DNA that may lead to cancer in the human body (Kumar, 2014).

The vitamin A content of the raw sample was 1.95 mg/100g and that of the processed flour samples ranged from 1.37–1.86 mg/100g with the boiled sample having the least value (1.37 mg/100g), while the autoclaved flour had the highest value (1.86 mg/100g) which was lower than the value of the raw flour sample (1.95 mg/100g). There were significant differences (p<0.05) in the Vitamin A content of the flour samples. The result showed that autoclaving and roasting treatments showed a significant (p<0.05) increase in vitamin A content of the flours than the boiling and blanching techniques when compared to the raw sample. The decrease in the Vitamin A contents of boiled and blanched flour samples could be due to treatment effects caused by the degradation and oxidation of this vitamin during processing (Akubor, 2016). This result is in agreement with the findings of Olanipekun *et al*. (2015) who reported that boiling and blanching had deleterious effects in reducing the vitamin A content of kidney bean flour. Vitamin A helps in the maintenance of good sight. It is also known as a potential antioxidant which helps to fight diseases such as cancer and diabetes in the human body (Okaka *et al*., 2006, Olanipekun *et al*., 2011).

The vitamin E content of the processed African yam bean flour samples ranged from 1.27–1.53 mg/100g and that of the raw sample was 1.66 mg/100g. The boiled sample had the least value (1.27 mg/100g), while the autoclaved sample had the highest value (1.53 mg/100g) which was also lower than the vitamin E content (1.66 mg/100g) of the raw flour sample. The boiled and blanched flour samples showed a significant (p<0.05) difference in vitamin E content, while roasted and autoclaved flours had no significant (p>0.05) difference between the samples. The vitamin E content (1.27–1.53 mg/100g) obtained in this study was lower than the values (1.45–2.68 mg/100g) reported by Ene-Obong and Obizoba (2009) for cooked and soaked cowpea flours. Vitamin E acts as a powerful antioxidant in the body. It is also important in the maintenance of healthy brains, eyes, immune systems and hearts. It also helps to strengthen the body’s natural defence against illness and infection. Generally, roasting and autoclaving greatly enhanced the vitamin contents of the flour samples than the boiling and blanching treatments.

Anti-nutrient composition of raw and processed African yam bean flour samples

The anti-nutrient contents of raw and processed African yam bean flour samples are presented in Table 4. The trypsin inhibitor activity of the raw sample was 6.45 Tiu/g and that of the processed samples ranged between 0.33–0.58 Tiu/g with the autoclaved sample having the least value (0.33 Tiu/g), while the blanched sample had the highest value (0.58 Tiu/g) which was significantly (p<0.05) lower than that of the raw sample (6.45 Tiu/g). There were significant (p<0.05) differences in the trypsin inhibitor activity of the flour samples. The result showed that autoclaving significantly (p<0.05) reduced the trypsin inhibitor activity of the flour compared to the boiling, roasting and blanching treatments. The observation is in line with the reports of Ahamefule and Odoemelam (2008) for boiled and toasted *Canavalia Plagiosperma* seed flours. It also collaborates with the views of other workers (Akinmutimi, 2007; Oraka and Okoye, 2017) who reported that wet or moist heat treatment is an effective means of inactivating trypsin inhibitors. Trypsin inhibitors are natural organic compounds that interact with proteolytic enzymes particularly trypsin and chymotrypsin which are responsible for protein digestion. Trypsin inhibitors which are antinutrients for man and other monogastric animals do not exert any adverse effect on ruminants because they are degraded in the rumen (Anya and Ozung, 2019). In monogastric, hypertrophy of the pancreas is one of the primary physiological effects of trypsin inhibitors. Anwuoye *et al*. (2012) were of the opinion that pancreatic hypertrophy leads to an excessive loss of endogenous protein secreted by the pancreas. Since this protein which consists of largely pancreatic enzymes is rich in cysteine, the effect is a net loss of sulphur–containing amino acids in the body. Generally, trypsin inhibitor was found to be the most heat-labile antinutrient in African yam bean seed flours. Trypsin inhibitors which interfere with tryptic digestion associate with proteinases in a definite ratio to produce complexes which show no proteolytic activity and so inactivate the proteolytic enzymes that are capable of degrading proteins into amino acids (Agiang *et al*., 2010; Anya and Ozung, 2017; Eze *et al.,* 2024). However, the values (0.33–0.56 Tiu/g) obtained for processed African yam bean flours in this study were generally lower than the recommended safe levels of 2.17–4.93 Tiu/g for trypsin inhibitor activity. Therefore, processed African yam bean flours are safe and would not pose any problem to human life when consumed.

The tannin content of the samples was highest (5.23 mg/100g) in the raw flour and lowest (1.09 mg/100g) in autoclaved African yam bean flour. Autoclaving was capable of reducing the level of tannin in African yam bean seeds which could in turn make available the nutrients that are inhibited by tannin in African yam bean flour. The result showed that autoclaving and boiling treatments drastically reduced the level of tannin in African yam bean flours compared to the samples processed by roasting and blanching which had the values of 1.17 and 1.38 mg/100g, respectively. The decrease could be attributed to the ability of autoclaving and boiling methods to easily break down the linkage formed by tannic acid and to overcome the intramolecular forces existing with the tannin structure than the roasting and blanching techniques during processing. However, this improves the rate of molecular

Table 4. Anti-nutrient composition of raw and processed African yam bean flour samples.

Parameters	Raw	Blanched	Boiled	Roasted	Autoclaved
Trypsin inhibitor (Tiu/g)	$6.45^{a}\pm0.01$	$0.58^{b} \pm 0.01$	0.36^{d} 0.01	$0.44^{c} \pm 0.04$	$0.33^{e} \pm 0.01$
Tannin (mg/100g)	$5.23^{a} \pm0.02$	$1.38^{b} \pm 0.02$	$1.17^{d} \pm 0.02$	$1.22^{c} \pm 0.07$	$1.09^{e} \pm0.04$
Phytate (mg/100g)	$9.78^{a} \pm0.01$	$2.00^{b} \pm 0.01$	$1.03^{d} \pm0.01$	$1.09^{c} \pm 0.03$	$1.02^{d} \pm 0.02$
Oxalate (mg/100g)	$7.21^{a} \pm 0.01$	$2.03^{b} \pm 0.23$	$1.25^{d} \pm 0.02$	$1.80^{c} \pm 0.38$	$1.15^{e} \pm 0.13$
Saponin (mg/100g)	$4.72^{a} \pm0.00$	$1.88^{b} \pm 0.12$	$1.45^{d} \pm0.06$	$1.56^{c} \pm0.02$	$1.22^{e} \pm0.01$
Haemaglutinin (Hui/g)	$5.31^{a} \pm0.42$	$2.12^{b} \pm 0.02$	$1.56^{d} \pm 0.01$	$1.78^{c}\pm0.42$	$1.55^{d} \pm0.14$

Values are mean ± standard deviation of triplicate determinations. Means within the same row with different superscripts are significantly different at $p<0.05$.

thermo–disintegration which results in better elimination of tannins. This further suggests better digestibility of protein when autoclaved and boiled African yam bean flours are used in food preparations than roasted and blanched flours because tannic acid is known to adversely affect protein digestibility in man and other monogastric animals (Ukachukwu *et al.,* 2002). The tannin content (1.09–1.38 mg/100g) obtained in this study was also higher than the value (0.08 mg/100g) reported by Akinmutimi (2007) for cooked *Mucuna puriens* seed flour. Tannins at their safe level (0.82–7.53 mg/kg) have some health benefits. They also play significant roles in the prevention of cavities, diarrhoea, tooth decay and heart diseases. Tannins are known to reduce protein metabolism by forming complexes with protein which in turn leads to a remarkable decrease in its digestibility and palatability (Osagie, 1998; Oraka and Okoye, 2017). Tannins are water-soluble phenolic compounds with a high molecular weight (>500) and have the ability to precipitate protein particularly pepsin in man (Kumar,1991). However, in ruminants, condensed tannins have been shown to be beneficial because the protein–tannin complex in the rumen usually dissociates after digestion as a sort of by-pass protein and the effect of its presence is therefore negligible (Adegunwa *et al*., 2012). The levels of tannin in all the processed samples were relatively below the safe level of 0.82 to 7.53 mg/kg.

The phytate content of the raw sample was 9.78 mg/100g and that of the processed samples ranged from 1.02 to 2.00mg/100g. The autoclaved sample had the lowest value (1.02 mg/100g), while the blanched African yam bean flour had the highest value (2.00 mg/100g) which was significantly ($p<0.05$) lower than that of the raw sample (9.87 mg/100g). There were significant differences ($p<0.05$) in the phytate content of the flour samples except for boiled and autoclaved samples which showed no significant ($p>0.05$) difference. The apparent decrease in phytate content of boiled and autoclaved flours could be attributed to the formation of insoluble complexes caused by the interactions of phytic acid with other components such as phytate, protein and phytate-mineral complexes (Sandberg, 2002). The result is also in agreement with the findings of Ene-obong and Obizoba (1996) who reported a reduction in the phytate content of boiled African yam bean flour. Phytate lowers the bioavailability of certain minerals such as zinc, calcium and iron thus making them nutritionally unavailable to the body. Obasi and Wogu (2008) reported that the maximum tolerable dose of phytate in the body is between 250 and 500 mg/100g. Therefore, the phytate levels of the flour samples obtained in this study were generally below the recommended safe level. Phytates are known to increase the requirements for minerals, especially phosphorus, which forms insoluble complexes with phytic acid because of its special affinity for this metal ion and zinc (Tulen *et al*., 2008; Agiang *et al*., 2010). However, autoclaved and boiled Africa yam bean flours significantly ($p<0.05$) had lower phytate contents compared to the roasted and blanched samples. Thus, one may conclude that autoclaved and boiled flour samples were better detoxified compared to other treatments during processing.

The oxalate content of the raw flour sample was 7.21 mg/100g and that of the processed samples ranged between 1.15–2.03 mg/100g with the autoclaved sample having the least value (1.15mg/100g), while the blanched had the highest value (2.03 mg/100g) which was significantly ($p<0.05$) lower than the value of raw flour sample (7.21 mg/100g). The oxalate content (1.15–2.03 mg/100g) obtained for the processed flour samples in this study was significantly ($p<0.05$) lower than the values (1.58–2.48 and 1.84–2.88 mg/100g) reported by Umoren *et al*. (2007) and Yusuf *et al*. (2008) for boiled horse eye bean and roasted Bambara groundnut flours, respectively. The reduction in the oxalate contents of autoclaved and boiled flours is in agreement with the report of Beckley and Joseph (2012) who stated that autoclaving and boiling treatments had the capacity to reduce the oxalate content of African yam bean flours more readily than roasting and blanching treatment during processing. Oxalates affect the metabolism of calcium, magnesium and protein in man and other monogastric animals. They also react with calcium to form calcium oxalates which are responsible for the formation of kidney stones in humans (Savita *et al*., 2014). Generally, the levels of oxalate in all the processed flour samples were within the safe level (0.14–4.72 mg/kg) which is an indication that they are safe for use in the formulation of foods for humans. At low levels, oxalate in food is known to cause no irritation in the mouth or interfere with the absorption of iron and calcium in the body (Jacob *et al*., 2015). It has been also shown that oxalates produce irritation in the mouth and prevent the absorption of calcium and iron in foods (Onyeike and Omubo-Dede, 2002). Onyeike *et al.* (1999) showed that the most obvious effect of oxalate toxicity was on calcium metabolism as it combines with serum calcium to form an insoluble calcium oxalate complex which brings about a reduction in serum calcium level and violent muscular stimulation with convulsion and eventual collapse. The reduction of oxalate to a physiologically safe level by autoclaving, boiling, roasting and blanching treatments may, therefore enhance cellular utilization of divalent metal ions as cofactors for the metabolic activities of some enzymes.

The raw sample had the saponin content of 4.72 mg/100g and that of the processed samples ranged from 1.22–188 mg/100g with the autoclaved sample having the least value (1.22 mg/100g), while the blanched sample had the highest value (1.88 mg/100g) which was significantly ($p<0.05$) lower than that of the raw sample (4.72 mg/100g). The saponin content (1.22–1.88 mg/100g) obtained for the processed flour samples in this present study was comparable to the value (0.39–2.97 mg/100g) reported by Nwanekezi *et al*. (2017) for boiled and roasted pigeon pea flours. There were significant differences in the saponin content of the flour samples. The decrease in the saponin content of the processed flour samples compared to the raw sample could be generally due to treatment effects caused by the scorching effect of heat and leaching as a result of heat sensitive nature of saponins during processing. Saponins are known to have cholesterol-binding properties and haemolytic activities on red blood cells (Sadipo *et al*., 2000). Also, saponins when extracted and purified can be used for the preparation of certain hormonal and fertility drugs (Sreeramulu *et al*., 2009). The recommended safe level of saponin in food is between 0.22 and 6.39 mg/kg and at this level, it has the ability to reduce the level of blood lipids and possess an antioxidant effect in humans. Saponins are toxins found as non-cardic steroid glycosides that produce lather, have bitter taste and characteristically haemolyze red blood cells or erythrocytes (Yusuf *et al*., 2008). They are used in the production of soft drinks, beer, confections and other food products since they stabilize aqueous solutions and suspensions of oil.

The haemagglutinin content of the raw flour was 5.31 Hui/g and that of the processed samples ranged from 1.55 to 2.12Hui/g with the autoclaved sample having the least value (1.55 Hui/g), while the blanched sample had the highest value (2.12 Hui/g) which was significantly ($p<0.05$) lower than that of the raw sample (5.31 Hui/g). There were significant differences ($p<0.05$) in the haemagglutinin content of the flour samples except for autoclaved and boiled flour samples which had similar values. The lower values of haemagglutinin (1.55–2.12 Hui/g) obtained for the processed samples were comparable to the values (1.58–2.16 Hui/g) reported by Anya and Ozung (2019) for boiled and roasted African yam bean flours. Ene-Obong and Obizoba (2009) also reported that dehulling in combination with heat treatment such as boiling, blanching, autoclaving and roasting resulted in a greater reduction of the anti-nutrient contents of African yam bean flours. Haemagglutinins are known to exert deleterious effects through the structural and functional disruptions of the intestinal microvilli which resulted in reduced nutrient absorption. The seeds of many edible legumes have long been known to contain haemagglutinins which are glyco-proteins that have the ability to agglutinate erythrocytes or red blood cells (Okaka *et al*., 2006). Some of these haemagglutinins have been suggested to contribute to the poor nutrient quality of raw beans (Jacob *et al*., 2015). The values (1.55–2.12Hiu/g) reported in this study for the processed African yam bean flours were within the recommended safe level (0.14–4.72Hiu/g) for haemagglutinins in foods**.** Generally, autoclaving and boiling treatments have greater effects in reducing the anti-nutrient contents of African yam bean flours than the roasting and blanching methods.

Conclusion

The study showed that thermal processing greatly affected the proximate, mineral, vitamin, and anti-nutrient contents of the processed African yam bean flour compared to the raw flour sample. The result showed that blanching and boiling treatments had greater effects in reducing the protein, fat, ash, crude fibre, mineral and vitamin contents of processed African yam bean flours with a slight increase in their carbohydrate and energy contents than the roasting and autoclaving processes when compared with the raw samples. In addition, the result also showed that all the processing treatments (boiling, blanching, roasting and autoclaving) employed in the processing of African yam bean flours drastically reduced the levels of antinutrients found naturally in African yam bean seeds. However, autoclaving and boiling treatments had greater effects in reducing the antinutrient contents of processed African yam bean flours than the roasting and blanching treatments compared to the raw flour sample. Generally, the study revealed that the flours could be used as substitutes for wheat flour or in the formulation of composite flours with other non-wheat flours in the preparation of a wide range of food products such as biscuits, cookies, snacks and complementary foods because of their nutritional quality.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

Adegunwa, M. O. Adebowale, A. A., & Solana C. O. (2012). Effect of thermal processing on the biochemical composition, anti-nutritional factors and functional properties of benised (*Sesamum indicum*) flour. *American Journal of Biochemistry and Molecular Biology*, *2*(3), 175-182.

Agiang, M. A., Umoh, I. B., Essien, A. I., & Eteng, M. U. (2010). Nutrient changes and antinutrient contents of beniseed and beniseed soup during cooking using a Nigerian traditional method. *Pakistan Journal of Biological Sciences*, *13*(20), 1011-1015.

Ahamefule, F. O. (2005). Evaluation of pigeon pea cassava-based diets for goat production in south eastern Nigeria. A Ph.D. Thesis, Department of Animal Science, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. Pp. 78-86.

Ahamefule, F. O., & Odoemelam, V. U. (2006). Effect of dehulling on the proximate composition, antinutritional properties and mineral content of *canavalis plagiosperma* seed. *Tropical Journal of Animal Science, 9*(2), 35-43.

Ahamefule, F. O., & Odoemelam, V. U. (2008). Effect of soaking duration on the proximate composition, gross energy, mineral content and some anti-nutritional properties of *Canavalis plagiospera*. *Proceedings of the 13th Annual Conference of Animal Science Association of Nigeria, ABU Zaria, Nigeria.* Pp. 491-494.

Ajayi, A. O. (2011). Sustainable dietary supplements: an analytical study of African yam bean (*Sphenostylis stenocarpa)* and corn (*Zea mays*). *European Journal of Experimental Biology, 1*(4), 189-201.

Akinmutimi, A. H. (2007). Effect of cooking period on the nutrient composition of velvet beans (*Mucuna pruriens*). *Proceedings of the 32nd Annual Conference of the Nigeria Society of Animal Production*. University of Calabar, Nigeria. Pp. 223-236.

Akubor, P. I. (2016). Effect of fermentation on the proximate composition, functional and sensory properties of complementary foods prepared from cowpea and sweet potato flour blends. *Nigerian Journal of Nutritional Sciences, 37*(2), 117-724.

Akubor, P. I. (2017). Effect of processing methods on the chemical composition and functional properties of pigeon pea seed. *Innovare Journal of Food Science, 5*(4), 16-19.

Alayande, I. B., Mustapha, K. B., Dabak, J. D., & Ubon, G. A. (2012). Comparison of nutritional values of brown and white beans sold in Jos North Local Government Markets, Plateau State, Nigeria. *African Journal of Biotechnology, 11*(43), 10135-10140.

Alwood, A. K., Sims, R. C., & Guraya, H. S. (2006). Effects of microwave heat-moisture treatment on properties of waxy and non-waxy rice starches. *Food Chemistry*, *97*(2), 318-323.

Anwuoye, J. C., Jigam, A. A., & Ndaceko, G. M. (2012). Effects of extrusion cooking on the nutrient and anti-nutrient composition of pigeon pea and unripe plantain flour blends. *Journal of Applied Pharmaceutical Sciences; 2*(5), 158-162.

Anya, M. I. (2012). Evaluation of African yam bean (*Sphenostylis stenocarpa)* seed meal as feed stuff for goat production in humid zone of Nigeria. A Ph.D. Thesis, Department of Animal Production and Livestock Management, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. Pp. 122-132.

Anya, M. I., & Ozung, P. O. (2019). Proximate, mineral and anti-nutritional compositions of raw and processed African Yambean (*Sphenostylis stenocarpa*) seeds in Cross River State, Nigeria. *Global Journal of Agricultural Sciences*, *18*(1), 19-29.

AOAC (2010). *Official methods of analysis,* 18th edition*.* Association of Analytical Chemists, Washington D.C. Pp. 200-523.

Arawande, J. C., & Borokini, F. B. (2010). Comparative study of chemical composition and functional properties of three Nigerian legumes (Jackbean, pigeon pea and cowpea). *Journal of Emerging Trends in Engineering and Applied Sciences, 1*(1), 89-95.

Arukwe, D. C., Nwanekezi, E. C., & Agomuo, J. K. (2017). Effect of combined processing methods on the functional and pasting properties of pigeon pea (*Cajanus cajan*) flour. *International Journal of Science and Qualitative Analysis, 3*(3), 23-30.

Asoiro, F. U., & Ani, A. O. (2011). Determination of some physical properties of African yam bean. *Pacific Journal of Science and Technology*, *12*(1), 374-380.

Azeke, M. A., Fretzdoff, B., Beuning, C., Pfaue, W., Holfzapfel, W., & Betsche. T. (2005). Nutritional value of African yam bean (*Sphenostylis stenocarpa*): Improvement by lactic acid fermentation. *Journal of the Science of Food and Agriculture, 85*(6), 963-970.

Beckley, I. I., & Joseph, K. M, (2012). Genetic assessment of three colour variants of African yam bean (*Sphenostylis stenocarpa*) commonly grown in the midwestern region of Nigeria. *International Journal of Modern Botany, 2*(2), 13-18.

Carew, L. B., Hardy, D., Weis, J., Alster, F., Mischler, S. A., Gernat, A., & Zakrzewska, E. I. (2003). Heating raw velvet beans (*Mucuna pruriens*) reverses some anti-nutritional effects on organ growth, blood chemistry, and organ histology in growing chickens. *Tropical and Subtropical Agroecosystems*, *1*(2-3), 267-275.

Chinma, C. E., Adewuyi, O., & Abu, J. O. (2009). Effect of germination on the chemical, functional and pasting properties of flour from brown and yellow varieties of tiger nut (*Cyperus esculentus*). *Food Research International*, *42*(8), 1004-1009.

Chinwendu, J. N. Obiakor, O., Philomena, N., & Maduforo, A. N. (2014). Effect of fermentation on the nutrient antinutrient composition of African yam bean (*Sphenostylis stenocarpa*) seeds and pearl millet (*Pennisetum glaucum*) grains. *International Journal of Science and Technology, 2*(12), 169-178.

Ene-Obong, H. N., & Obizoba, I. C. (1996). Effect of domestic processing on the cooking time, nutrients, antinutrients and *in vitro* protein digestibility of the African yam bean (*Sphenostylis stenocarpa*). *Plant Foods for Human Nutrition*, *49*(1), 43-52.

Ene-Obong, H. N., & Obizoba, I. C. (2009). Anti-nutrient contents and *in vitro* digestibility of African yam bean, pigeon pea and cowpea. *Plant Foods for Human Nutrition, 93*(30), 225-233.

Etong, V. A., Akinlade, J. T. B., & Moronfola, A. O. (2013). Comparative study of the effect of dietary replacement of 15% maize offals with either pigeon pea (*Cajanus cajan*) grain or leave meal on performance of weaner rabbits. Proceedings of the 38th Annual Conference of the Nigeria Society for Animal Production, University of Calabar, Nigeria. Pp. 217-219.

Eze, O. C., Onwuchuruba, C. F., & Ahamelufe, K. U. (2019). Replacement value of soybean meal with raw or boiled pigeon pea seed meal in exotic pullet diets. *Nigerian Journal of Animal Science, 15,* 37-48.

Eze, S. I., Okoye, J. I., & Onwuama, N. N. (2024). Effect of germination time on the properties of flours from red and brown varieties of pigeon pea (*Cajanus cajan)* seeds. *International Journal* of *Biochemistry Research and Review, 33*(3), 49-62.

Fadahunsi, I. F. (2009). The effect of soaking, boiling and fermentation with Rhizopus oligosporus on the water soluble vitamin content of Bambara groundnut. *Pakistan Journal of Nutrition*, *8*(6), 835-840.

Gbenga-Fabusiwa, F. J. (2021). African yam beans (*Sphenostylis stenocarpa*): A review of a novel tropical food plant for human nutrition, health and food security. *African Journal of Food Science*; *15*(2), 33-47.

Graham, R. D., & Welch, R. M. (1996). Breeding for micronutrients in staple food crops from a human nutrition perspective. *Journal of Experimental Botany*; *55*(3), 353-364.

Jacob, A. G., Etong, D. I., & Tijjani, A. (2015). Proximate, mineral and anti-nutritional compositions of melon (*Citrullus lanatus*) seeds. *British Journal of Research, 2*(5), 142-151.

Kumar, R. (1991). Anti-nutritional factors, the potential risk of toxicity and methods to alleviate them. In: legume trees and other fodder trees as protein sources for livestock. A Speedy and P. Pugliese (eds). Proceedings of the FAO expert consultation held in Kuala Lumpar, Malaysia, *FAO Animal and Health Paper* 102, FAO, Rome. Pp. 25-32.

Kumar, S. (2014). The importance of antioxidant and their role in pharmaceutical science: a review. *Asian Journal of Research in Chemistry and Pharmaceutical Sciences, 1*(1), 27-44.

Mbah, B. O., Eme, P. E., & Ogbusu, O. F. (2012). Effect of cooking methods (boiling and roasting) on the nutrient and antinutrient contents of *Moringa oleifera seeds. Pakistan Journal of Nutrition, 11*(3), 211-215.

Ndidi, U. S., Ndidi, C. U., Olagugu, A., Muhammad, A., Graham Billy, F., & Okpe, O. (2014). Proximate, anti-nutrients and mineral contents of raw and processed (boiled and roasted) *(Sphenostylis stenocarpa)* seeds from southern Kaduna, northwest, Nigeria. *Journal of Food Science and Nutrition, 12*(3), 9-14.

Nsa, E. E. (2008). Chemical and biological assay of castor oil meal (*Ricinus communis*) as an alternative nutrient source in pullet bird's diets. A *Ph.D Thesis. Department of Animal Nutrition and Forage, Micheal Okpara University of Agriculture, Umudike, Abia State, Nigeria.* Pp. 73-79.

Nsa, E. E., & Ukachukwu, S. N. (2009). Effect of thermal processing methods on the proximate composition, gross energy, minerals and ricin content of undecorticated castor oil seed (*Ricinus communis*). *Global Journal of Agricultural Sciences, 8*(2), 223 -227.

Nwanekezi, E. C., Ehirim, F. N., & Arukwe, D. C. (2017). Combined effects of different processing methods on vitamins and antinutrients contents of pigeon pea (*Cajanus cajan*) flour. *Journal of Environmental Science, Toxicology and Food Technology*, *11*(4), 73-81.

Obasi, N. E., & Wogu, C. O. (2008). Effect of soaking time on proximate and mineral compositions and anti-nutritional factors of yellow maize (*Zea mays*). *Nigerian food Journal, 26*(2), 47738-47739.

Okaka, J. C., Akobundu, E. N. T., & Okaka, A. N. T. (2006). *Food and Human Nutrition. An Integrated Approach.* Ocjano Academic Publishers, Enugu, Nigeria. Pp. 373-386.

Olanipekun, O. T., Obatolu, V. A., Ejoh, S. I., Oyarekua, M. A., & Farinde, E. C. (2011). Evaluation of the nutrient and antinutrient contents of two Nigerian under-utilized legumes. *Moore Journal of Agriculture and Research, 12*, 56-63.

Olanipekun, O. T., Omenna, E. C., Olapade, O. A., Suleiman, P., & Omodara, O. G. (2015). Effect of boiling and roasting on the nutrient composition of kidney beans seed flour. *Sky Journal of Food Science*, *4*(2), 024-029.

Onuoha, C. H., Harry, B. J., & Eze, S. O. (2017). Evaluation of nutrient and anti-nutritional factors of different species of African yam bean (*Sphenostylis stenocarpa*). *European Journal of Basic and Applied Sciences, 4*(1), 2059-2068.

Onwuka, G. I. (2005). *Food Analysis and Instrumentation: Theory and practice*. Naphthali Publishers Ltd, Lagos, Nigeria. Pp. 95-96.

Onyeike, E. N., & Omubo-Dede, T. T. (2002). Effect of heat treatment on the proximate composition, energy values, and levels of some toxicants in African yam bean (*Sphenostylis stenocarpa*) seed varieties. *Plant Foods for Human Nutrition*, *57*, 223-231.

Onyeike, E. N., Abbey, B. W., & Anosike, E. O. (1991). Kinetics of heat-inactivation of trypsin inhibitors from the African yam bean (*Sphenostylis stenocarpa*). *Food Chemistry*, *40*(1), 9-23.

Oraka, C. O., & Okoye, J. I. (2017). Effect of heat processing treatments on the nutrient, anti-nutrient contents and functional properties of lima bean (*Phaseolus lunatus*) flour. *International Journal of Food Science and Nutrition, 2*(3), 13-17.

Osagie, A. U. (1998). Antinutritional factors. In: Osagie, A. U., & Eka, O. U. (eds.). *Nutritional quality of plant foods*. Post-Harvest Unit, Department of Biochemistry, University of Benin, Benin City Nigeria. Pp. 221-232.

Potter, N. N., & Hotchkiss, J. H. (2006). *Food science text series,* 5th edition. CBS Publishers and Distributors, New Delhi, India. Pp. 124-142.

Sadipo, O. A., Akiriyi, Y.A., & Ogunbanosu, Y. U. (2000). Studies on certain characteristics of extracts or barks of *pansinystaliam acruceras* (K. schem) piere, exbeila. *Global Journal of Pure and Applied Sciences, 6*(1), 83 -88.

Sandberg, A. S. (2002). Bioavailability of minerals in legumes. *British Journal of Nutrition*, *88*(3), 281-285.

Savita, R., Gagan, P., Rajesh, Y., & Deen, M.K. (2014). Screening of pigeon pea (*Cajanus cajan* L.) seeds for study of their flavonoids, total phenolic content and antioxidant properties. *International Journal of Pharmaceutical Sciences Review and Research*, *28*(2), 90-94.

Seena, S., Sridhar, K. R., Arun, A. B., & Young, C. C. (2006). Effect of roasting and pressure-cooking on nutritional and protein quality of seeds of mangrove legume *Canavalia cathartica* from southwest coast of India. *Journal of Food Composition and analysis*, *19*(4), 284-293.

Sreeramulu, D., Vigaya, C. K. R., & Rajhunah, M. (2009). Antioxidant activity of commonly consumed cereal, millets, pulses and legumes in India. *Indian Journal of Biochemistry and Biophysiology,* 46, 112-118.

Thomas, B., Marshal, A., Hans, B. P., & Barabra, F. (2005). Food safety and security: Fermentation as a tool to improve the nutritional values of African yam bean. *In: Proceedings of International Agricultural Research for Development Stuttgart Hohenheim. Tropentag.* Pp. 27-30*.*

Tulen, C. D., Carew, S. N., & Ajiji, I. (2008). The feed value of velvet beans (*Mucuna pruriens)* for laying chickens. *Proceedings of the 33rd Annual Conference of the Nigeria Society for Animal Production.* Olabidi Onabanjo University, Ayetoro, Ogun State, Nigeria. Pp. 405-408.

Uche, S. N., Charity, U. N. Abbas, O. Aliyu, M. Francis, G. B., & Oche, O. (2014). Proximate, antinutrients and mineral composition of raw and processed boiled and roasted (*Sphenostylis stenocarpa*) seeds from Southern Kaduna, North West, Nigeria. *International Scholarly Research Notices, 20*(4) 280-287.

Uherova, R., Hozova, B., & Sminox, V. (1993). The effect of microwave heating on the retention of some B – vitamins. *Food Chemistry*, 46, 293-295.

Ukachukwu, S. N. (2000). Chemical and nutritional evaluation of *Mucuna cochinchinensis* Bean as alternative protein ingredient in broiler diets. *A Ph.D. Thesis.* Department of Animal Science, Faculty of Agriculture, University of Nigeria, Nsukka.

Ukachukwu, S. N., & Obioha, F. C. (2000). Effect of time duration of thermal treatments on the nutritive value of *Mucuna cochinchinensis*. *Global Journal of Pure and Applied Sciences*, *6*(11), 11-15.

Ukachukwu, S. N., Ezeagu, I. E., Tarawali, G., & Ikeorgu. J. E. G. (2002). Utilization of *Mucuna* as food and feed in West Africa. *Proceedings of an International Workshop. Tegucigalpa; April, 26-29, 2002 Honduras. CIEPCA and Judson College Honduras*. Pp. 189-127.

Umoren, U. E., Effiong, O. O., & Akpam, I. A. (2007). Nutritional evaluation of the horse eye bean (*Mucuna urena):* effect of processing on the chemical composition. *Journal of Food Agriculture and Environment, 5*(2), 128-131.

Yusuf, P. A., Egburu, F. A., Egwueh, S. I. D., Pega, G. L., & Adiukwu, M. O. (2013). Evaluation of complementary food prepared from sorghum, African yam bean (*sphenostylis stenocarpa)* and mango mesocarp flour blends. *Pakistan Journal of Nutrition, 12*(2), 205-208.