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Effect of processing and substitution levels of *Ukwa* (*Treculia africana*) on the anti-nutrient factors, *in-vitro* starch and protein digestibility and total essential amino-acid content of snack bars

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Introduction: *Ukwa* (*Treculia africana*) is an indigenous edible seed. It is a strategic store of vital food nutrients that are available during a specific crucial time of the year when reliable sources of these nutrients are under cultivation and extremely scarce. In the past, only poor rural residents used to eat it, but today it is not only a specialty meal enjoyed by Nigeria's elite and metropolitan residents but also a source of foreign exchange.

Methods: In this study, *Ukwa* was processed into whole, dehulled, malted and defatted flours. Maize and coconut flours were blended with the respective *Ukwa* flours at the ratio of 0:95:5, 20:75:5, 25:70:5, 30:65:5, 35:60:5 and 95:0:5 for *Ukwa* flour:Maize flour:Coconut grits respectively for development of snack bars. A two-factor factorial experiment in a completely randomized block design was applied for the study of the effect of processing, substitution levels of *Ukwa* flour and the interaction of the two variables on the responses analyzed. Anti-nutrient content and proximate compositions of the flours were determined using standard procedures.

Results: Processing significantly reduced the anti-nutrient content and increased protein content of *Ukwa* flours. Up to 51.72% reduction of tannin was obtained by dehulling. Defatting, malting and dehulling resulted in 18.75, 34.37 and 65.62% reduction respectively in oxalate content. Highest reduction was obtained by dehulling, and was 70.69% in phytate, 79.95% in saponin, and 48.17% in trypsin inhibitor activity. Crude protein content of snack bars had 16.16 to 25.46% substitution main effect, and 19.43 to 22.65% processing main effect. *In-vitro* protein and starch digestibility increased with processing and decreased with increase in substituted level of *Ukwa* in the blend. Improvement, up to 9.97% by dehulling, 9.86% by malting and 8.64% by defatting, was recorded in *in-vitro* protein digestibility. An increase of 3.00 to 24.10% by defatting, 5.90 to 29.09% by malting and 9.70 to 31.80% by dehulling was recorded in *in-vitro* starch digestibility.

Discussion: Our study revealed that, all the processing methods adopted reduced the anti-nutrient content of *ukwa* flours. Protein content and total essential amino-acid (TEAA) showed significant increase with increased substituted level of *ukwa* flour. *In-vitro* protein and starch digestibility decreased with increase substituted level of *ukwa* flour. Snack bars formulated with 20% *Ukwa* showed the highest *in-vitro* starch and protein digestibility irrespective of the method of processing. Malted *Ukwa* based snack bars recorded the highest values of TEAA. Processing of this nutritious seeds and use of its flour to develop snack bars could enhance utilization and give convenience to consumers and encourage extensive farming of the crop.

KEYWORDS

dehulling, sprouting, defatting, amino-acids, digestibility

Introduction

Food processing enhances the quality of food because, in the process, foodstuffs are made into forms that are more acceptable and different completely from the original food in appearance, taste, flavor, texture, and aroma. All food processing unit operations are procedures to achieve the desired changes in the raw materials. The combination of operations determines the nature of the final products (Brennan et al., 1970). Food processing is basically aimed at extending shelf-life by the use of preservatives to inhibit the growth of microbiological or occurrence of biochemical changes; eliminating anti-nutrient factors; removing contaminants from food; making available a wide variety of food products with attractive flavors, colors, aroma, and texture; and providing nutrients that are required for healthy living (Fellows, 1990; Enwere, 1998). Enhancing the qualities of food can be achieved through various means, such as drying, blanching, defatting, dehulling, fermenting, sprouting, or malting among other methods.

Convenience food is an eclectic category of processed food, manufactured for mass consumption, including chilled, dried, and canned foods; confectionary, snacks, and beverages; and processed meat, pasta, and cheese, ready to eat, ready to cook, and ready to serve. The very first definition of convenience food was proffered by Raj et al. (2021). They added that any food which has work prepared outside the home can be regarded as convenience food. According to Jabs and Devine (2006), convenience food is deemed as domestic outsourcing of food planning, preparation, and cooking. They also stressed that convenience food required very little preparation related to home cooking.

Ukwa (*Treculia africana*), commonly known as African breadfruit, is an evergreen tree with great potential as a source of nutrients to man (Osabor et al., 2009).

Ukwa is a rich source of protein (17–20%), carbohydrates (40%), oil (10%), and minerals such as magnesium, potassium, zinc, iron, calcium, sodium, copper, and vitamins (Osabor et al., 2009). Its protein has a fairly balanced composition of amino acids, with a lysine content higher than that in wheat (Nwabueze, 2007). In Nigeria, *Ukwa* is popular with the Igbo communities, and the seeds are eaten as snacks when toasted or roasted and as porridge when cooked with ingredients (Nwabueze et al., 2008). Its flour could be used as a soup thickener (Iwe and Ngoddy, 2000). As snacks, toasted *Ukwa* could be eaten with fresh maize or mature coconut. Runsewe et al. (2001) reported that *Ukwa* porridge improved the health conditions of malnourished children without any adverse effects. Despite its dense nutrient composition, *Ukwa* is under-utilized, partly because of the current lifestyle and demand for convenience, and the laborious steps and time involved in its processing. Expanding applications of *Ukwa* would increase its utility and versatility. One such application is processing into high fiber snack bars (Edima-Nyah et al., 2019), extruded snacks (Nwabueze et al., 2008), and malt for use in alcoholic beverages, and ethanol production (Nwabueze and Uchendu, 2011).

Maize (*Zea mays* L.) is a cereal with the highest production worldwide (Gwirtz and Garcia-Casal, 2014) and is extensively cultivated in Nigeria. Maize is considered a staple food generally in Africa, particularly in Nigeria. It feeds ~50% of the population. Maize is an important source of carbohydrates, proteins, and minerals such as iron and the B vitamins. There are ∼40 different ways of maize consumption recorded in African countries (Nago et al., 1990).

Coconut is respected in history because of its nutritious nature. It is rich in fiber, vitamins, and minerals. Due to the numerous health benefits derived from its nutritional content, coconut is regarded as a "functional food." Many food uses or products exist for coconut. The primary product is copra, and the white "meat" is found adhering to the inner wall of the shell. It can be dried to 2.5% moisture content, shredded, and used in candies and cakes, and other confections (Okafor and Ugwu, 2014). Coconut oil is expressed from copra, which is used in a variety of cooked foods and margarine production. Coconut is a source of quick energy for physical performance and athletic exercises (Bruce-Fife, 2010).

In view of the increasing demand for convenience foods, the objective of this study was to investigate the effect of processing and substituted levels of *Ukwa* (*Treculia africana*) on the anti-nutrient factors, proximate composition, *in vitro* protein digestibility, *in vitro* starch digestibility, and total essential amino acid content of the developed snack bars made from *Ukwa*, maize, and coconut to deliver a nutritious health product. The outcome of this study would help in determining the suitability of these developed snack bars as good complementary diets, increase utilization, and consumption beyond traditional ceremonies and attempt to make *Ukwa*-based snacks available to interested consumers.

Materials and methods

Source of raw materials

Ukwa was purchased from Ndoro market, Umudike, and Nigeria. Maize (white dent variety) was obtained from Uyo main market. Coconuts were obtained from a local farmer in Uyo, Nigeria.

Processing of whole *Ukwa* flour

Ukwa seeds were cleaned, parboiled for 15 min at 100°C, drained through stainless steel sieve, and allowed to cool. Parboiled *Ukwa* seeds were dried for 5 h at 60°C and toasted for 20 min at 150°C in an oven (Precision Compact, Model: PR305225M). Toasted seeds were milled using a Colombian Grain Mill (Victoria, Model: 530025) to flour. The whole *Ukwa* flour was stored in a clean container with a secured lid at room temperature (27 ± 2°C).

Processing of dehulled *Ukwa* flour

Ukwa seeds, previously washed and drained, were parboiled for 15 min at 100°C (for facilitating seed coat separation from the endosperm). Draining of parboiled seeds was done using stainless steel sieve and allowed to stand for 20 min to effect cooling and also soften the seed coat. Dehulling was performed by cracking the grains using Grain Mill (Victoria, Model: 530025, Colombia) and sorting to obtain clean dehulled seeds. Dehulled seeds were dried for 5 h at 60°C in an oven (Precision Compact, Model: PR305225M), and their temperature increased to 150°C for the toasting of the seeds for 20 min. Toasted seeds were milled to flour with a manual mill (Victoria Grain Mill, Model Ref: 530025), packaged, and stored at ambient temperature (27 ± 2°C) in a clean plastic container with a secured cover.

Processing of malted *Ukwa* flour

Processing procedures to obtain malted *Ukwa* flour (MUF) were carried out according to the method described by Edima-Nyah et al. (2022). The seeds were washed with potable water and steeped for 24 h, changing the liquor at 8-h intervals to reduce microbial load. This would prevent the embryo from suffocating due to the depletion of oxygen. Steeping was terminated by draining the liquor and spreading the seeds on a sterilized jute bag, placed on a laboratory bench. Germination was carried out at room temperature for 7 days and was terminated by kilning in an oven at 45°C for 12 h. The temperature was later increased to 60°C for 6 h for drying. The dried malted seeds were then toasted in the oven for 20 min at 150°C and milled to flour using a manual mill (Victoria Grain Mill, Model: 530025, Colombia). The flour was stored at ambient temperature (27 ± 2°C) in a clean, dry plastic container with a secured lid.

Processing of defatted *Ukwa* flour

Clean *Ukwa* was parboiled, drained, dried, toasted, and milled to flour using the same conditions described for whole *Ukwa* flour (WUF). The flour was defatted using the method described by Nwabueze and Iwe (2010) for defatting soybean flour. Food grade ethanol was used to soak the flour in the ratio of 1:3 for 3 h and centrifuged for 15 min at 4,000 rpm. The supernatant was decanted off leaving the semi-solid mass, after standing for some time. The semi-solid flour mass was then spread in pans and placed under the fan for 30 min to reduce the ethanol concentration therein. It was further dried for 24 h in an oven at 60°C to completely desolventizing the ethanol residue in the flour. The dried defatted flour was milled using a manual mill (Victoria Grain Mill, Model: 530025, Colombia) to break flour lumps. The dry defatted *Ukwa* flour (FUF) was packaged in a clean dry container with a secured lid, labeled, and stored at ambient temperature.

Processing of maize flour (MWF)

Maize grains were processed into flour according to the procedures outlined by Edima-Nyah et al. (2019).

Processing of coconut grits (COF)

Mature coconuts were harvested, dehusked, and cracked. Coconut flesh was removed manually from the hard endocarp using a stainless steel knife, with a sharp and pointed edge. The procedure, described by Edima-Nyah et al. (2019), was adopted for processing coconut grits.

Flour blend formulation

Processed *Ukwa* flour, maize flour, and coconut grits were blended in the ratio of 0:95:5, 20:75:5, 25:70:5, 30:65:5, 35:60:5, and 95:0:5.

Snack bar recipe

Six snack bar samples were prepared, each based on each of the composite flours previously blended. From each composite flour, 100 g of flour was weighed out. In addition, 25 g of caramel, 15 g of margarine, 10 g of coconut oil, 5 g of milk powder, 2 g of baking powder, 2 g of nutmeg, and 0.2 g of common salt were blended with 100 g of each composite flour. Each blend was mixed with 40 g of potable water.

Production of snack bars

Production of snack bars was according to the procedures described by Edima-Nyah et al. (2019). The flour and other baking ingredients were mixed manually in a stainless steel bowl for ∼3 min, for a uniform mixture. The liquid ingredients (coconut oil and caramel) were added next and mixed for another 3 min, and then, water was slowly added until the whole dough was mixed to obtain a uniform dough. The dough was placed in greased pans and compressed with a spatula to obtain a uniform mass and then covered. The dough was oven-baked at 150°C for 25 min. Products were cooled (∼60°C), de-panned, cut into bars (5 cm × 3 cm × 2 cm), dried to reduce the moisture content in an air-circulation oven for 6 h at 60°C, and packaged and stored at ambient temperature (27 ± 2°C) in the laboratory for further analyses.

Determination of anti-nutrient content

Tannin, phytate, and trypsin inhibitor activity contents of flour samples were determined by standard spectrophotometric methods of Pearson (1976). Oxalate and tannin determinations were determined by methods of Oberleas (1973) and Onwuka (2005), respectively.

Proximate analyses

The proximate composition of raw materials and snack bars was determined using standard methods (AOAC, 2005) for moisture content, and crude fat, crude protein, total ash, crude fiber, and carbohydrate and calorific (energy) values were calculated according to the method described by Osborne and Voogt (1978).

Determination of *in vitro* protein digestibility

An enzymatic method described by Kanu et al. (2009) was adopted for the determination of *in vitro* protein digestibility of snack bars produced.

Determination of *in vitro* starch digestibility

The method of analysis described by Singh et al. (2012), using enzymes, was used for the determination of *in vitro* starch digestibility of snack bars.

Determination of total essential amino acid

The amino acid profile of Snack bars produced was determined by the method of Benitez (1989). The samples were dried to a constant weight and hydrolyzed after defatting. Evaporation was carried out in a rotary evaporator, before loading into an applied bio-system (PTH) amino acid analyzer (model: 120A PTH, England). The total essential amino acid was calculated as the sum of cysteine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, tyrosine, and valine, as measured in g/100 g protein.

Data analysis

Data obtained were analyzed using IBM SPSS software, version 20, with two-way analysis of variance (ANOVA) for the determination of significance ($P < 0.05$) between means, and separated with the Duncan multiple range test.

Results and discussion

Anti-nutrient content of whole, dehulled, malted, and defatted *Ukwa* flours, Maize flour, and coconut grits

Anti-nutrient contents of flours are presented in Table 1. Tannin content ranged from 0.27% to 0.58%, with whole *Ukwa* flour (WUF) showing the highest and dehulled (DUF) showing the least concentrations, respectively. Processing significantly ($P < 0.05$) lowered tannin content. ∼32.76% reduction in tannin concentration of flour was recorded by defatting, 43.10% reduction by malting, and 51.72% reduction by dehulling. Percentage reduction by dehulling was higher than those reported in the literature by Alonso et al. (2000) in Faba bean (35% reduction in Shambat 616; 43% reduction in SML 85/1/1). The reduction in tannins by the dehulling process could be due to the removal of the hulls since most tannins are located in the hulls. The concentrations of tannins in the flour recorded in this study posed no health risk since the accepted lethal dose reported is 0.09% (Ifie and Emeruwa, 2011; Maseta et al., 2016). Tannins are high oligomeric molecules of polyphenol that occur in plants naturally (Adeoti et al., 2017). They inhibit digestive enzymes by binding with carbohydrates and proteins, thereby reducing their bioavailability (Ayodele and Kigbu, 2003).

Oxalate content in flours ranged from 0.11 mg/100 g to 0.33 mg/100 g (Table 1). Dehulled *Ukwa* flour showed the lowest value (0.11 mg/100 g) followed by the malted (0.21 mg/100 g) and defatted flour (0.26 mg/100 g) in increasing order. There was no significant difference between the defatted flour (FUF) and coconut grits (COF). WUF had the highest concentration (0.33 mg/100 g) of oxalate. Dehulling, malting, and defatting processes resulted in 65.62%, 34.37%, and 18.75% reduction in oxalate content of *Ukwa* flours. The amount of oxalate in the processed flours could not be toxic under meal portions since they were lower than the safe level (15–30 g/100 g food consumed) reported in the literature for a man (Coe et al., 2005).

The Phytate content of flours ranged from 2.09 mg/100 g to 7.42 mg/100 g. A significant difference ($p < 0.05$) existed in the phytate contents of all the flour samples. Maize flour (WMF) had the highest value (7.42 mg/100 g), followed by whole *Ukwa* flour (WUF), while dehulled flour (DUF) had the lowest value. ∼70.69% reduction was obtained by dehulling, while 52.73% and 21.18% reduction was obtained by malting and defatting processes, respectively. Thapliyal et al. (2014) reported a 14.39–20.87% reduction for chickpeas, and Wang et al. (2008) reported a decrease of 5.3–8.0% in field peas due to dehulling. The concentrations of phytate in the flours were lower than the considered lethal amount to human health, 250 mg/100 g, reported in the literature (Nagel, 2010; Maseta et al., 2016). According to Kumar et al. (2010), phytates, when at high levels in human foods, may limit the bioavailability and utilization of minerals such as iron, calcium, magnesium, and manganese by forming compounds that are insoluble and indigestible.

The saponin content of flours ranged from 2.23% to 11.12%. Dehulled *Ukwa* flour showed the lowest value, followed by the defatted flour (3.61%) and the malted (3.83%) in decreasing order. A significant difference existed in the saponin contents of all the flour samples. Whole *Ukwa* flour showed the highest value (11.12%), followed by maize flour (10.21%). The processing treatments resulted in a 79.95% reduction in saponin by dehulling, a 69.15% reduction by malting, and a 67.54% reduction by defatting. Adeoti et al. (2017) reported saponin content of 9.54–18.50 mg/100 g for Akee apple seed and ariel flour, while 5.20 mg/g was reported for flour from seeds of *M. utilis* (Seena, 2006). Saponin is known to have both bad and good effects on human health. By reacting with sterols on the membranes of erythrocytes, saponin shows hemolytic activities (Bauman et al., 2000) and has hypocholesterolemic properties (Oakfenfall and Sidu, 1990).

Trypsin inhibitor activity in the flours ranged from 0.95 TIU/mg to 13.76 TIU/mg. Coconut grits (COF) had the lowest (0.95 TIU/mg) concentration, followed by maize flour and WMF (1.03 TIU/mg) in increasing order. Whole *Ukwa* flour (WUF) had a significantly higher value (13.76 TIU/mg), followed by the MUF (10.81 TIU/mg) and FUF (10.04 TIU/mg) in decreasing order. Processing of *Ukwa* resulted in a 48.17% reduction by dehulling, 27.25% reduction by malting, and 27.11% reduction by defatting trypsin inhibitor factors. Thapliyal et al. (2014) reported a 7.72%−16.72% reduction after dehulling chickpea, while Wang et al. (2008) recorded a 5.3%−13.1% reduction in trypsin inhibitor after dehulling field pea. Steinkraus (2002) reported a decrease in the toxic effect of trypsin inhibitors due to sprouting.

Proximate composition and energy values of the whole, dehulled, malted, and defatted *Ukwa* flours, maize flour, and coconut grits

Moisture, ash, crude fat, crude fiber, crude protein, carbohydrate, and the energy value of the whole, dehulled, malted, and defatted *Ukwa* flours, maize flour, and coconut grits are shown in Table 2. The moisture content of *Ukwa* flour ranged from 3.48% to 3.80%, with dehulled flour having the lowest value. Coconut grits (COF) had the highest moisture,

TABLE 1 Anti-nutrient content of whole, dehulled, malted, and defatted *Ukwa* flours, maize flour, and coconut grits.

Flour sample	Tannin (%)	Oxalate (mg/100 g)	Phytate (mg/100 g)	Saponin (%)	Trypsin Inhibitor (TIU /mg)
WUF	$0.58^{a} \pm 0.01$	$0.32^{a} \pm 0.04$	$7.13^{b} \pm 0.10$	$11.12^{a} \pm 0.01$	$13.76^{a} \pm 0.02$
DUF	$0.28^{e} \pm 0.01$	$0.11^{d} \pm 0.03$	$2.09^{f} \pm 0.04$	$2.23^{f} \pm 0.01$	$7.82^{c} \pm 0.02$
MUF	$0.33^{c} \pm 0.03$	$0.21^{c} \pm 0.02$	$3.37^{e} \pm 0.01$	$3.43^{d} \pm 0.02$	$10.01^{b} \pm 0.04$
FUF	$0.39^{d} \pm 0.12$	$0.26^{b} \pm 0.10$	$5.62^{d} \pm 0.02$	$3.61^{e} \pm 0.05$	$10.04^{b} \pm 0.01$
WMF	$0.27^{e} \pm 0.01$	$0.31^{a} \pm 0.11$	$7.42^{a} \pm 0.01$	$10.21^{b} \pm 0.01$	$1.03^{d} \pm 0.01$
COF	$0.50^{b} \pm 0.04$	$0.27^{b} \pm 0.01$	$6.25^{c} \pm 0.03$	$7.21^{c} \pm 0.04$	$0.95^{e} \pm 0.00$

Values are mean ± standard deviation of triplicate determinations.

Means on the same column with different superscripts are significantly different at $P < 0.05$.

WUF, whole Ukwa flour; DUF, dehulled Ukwa flour; MUF, malted Ukwa flour; FUF, defatted Ukwa flour; WMF, maize flour; COF, coconut grits.

4.86%. Coconut has been shown to have hygroscopic or water-absorbing properties (Wasserman, 2016), and this could be the reason for having the highest moisture content. The moisture content obtained in this study was lower than those reported by earlier researchers: 9.00% for unmalted and 11.00% for malted African breadfruit seed flour by Nwabueze and Atuonwu (2007); 8.00% and 6.00% for unmalted and malted African breadfruit seed flour, respectively, by Nwabueze and Uchendu (2011), and 10.72% for raw, 9.64% for cooked, 7.70% for parboiled, and 6.80% for toasted African breadfruit seed flour by Emenonye (2016). Moisture content lower than 10% is considered within the standard category (James, 1995). The moisture content of flour samples may be of advantage in prolonged storage, with proper packaging (Rodge et al., 2012; Feili et al., 2013).

The Ash content of maize flour was 1.83%, while that of coconut grits was 6.28%. Malted *Ukwa* flour (MUF) showed the highest ash content (3.52%), followed by the dehulled (DUF, 3.29%), defatted (FUF, 3.07%), and whole (WUF, 3.14%). Dehulling, malting, and defatting significantly ($P < 0.05$) increased the ash content of *Ukwa*. Ash content is an estimation of the composition of minerals in a sample (Emenonye, 2016). Ash contents recorded in the study were higher than the results of earlier researchers: 2.50% and 2.75% for unmalted and malted African breadfruit seed flour reported by Nwabueze and Atuonwu (2007), 2.26% by Osabor et al. (2009), 2.80% for unmalted and 2.40% for malted reported by Nwabueze and Uchendu (2011), and 2.79% and 2.88% for raw and toasted seeds, respectively, as reported by Emenonye (2016). However, values close to those of this research were obtained by Nwabueze (2007) for raw African breadfruit seed flour (3.00%) and Emenonye (2016) for parboiled (3.22%) and cooked (3.52%) African breadfruit seed flour.

Crude fat content ranged from 5.83% to 11.52% in *Ukwa* flours. The fat contents of 11.52% for malted, 11.24% for whole, 11.09% for dehulled, and 5.83% for defatted samples were obtained. ∼a 48% reduction in fat was recorded by the defatting process. These fat contents were lower compared to those reported by Emenonye (2016) for raw (12.49%), parboiled (13.24%), and toasted (16.24%) African breadfruit seed flour. It was the same (11.45%) as reported by Nwabueze (2007). Maize flour showed the least value (4.79%), while coconut grits (42.12%) were the highest in fat content. The percentage of the crude fat content of coconut was highest because it was used as full-fat, not defatted.

Crude fiber content ranged from 7.73% to 20.18%. Maize flour had the lowest value (7.73%), followed by dehulled *Ukwa* flour (DUF) (7.77%) and coconut grits (10.67%). Gwirtz and Garcia-Casal (2014) reported about the same fiber value (7.3%) for maize flour. Malted *Ukwa* flour was observed to have the highest crude fiber content (20.18%). The high fiber contents of the *Ukwa* flour could have been a result of using the whole seeds (without removing the hulls) in the flour production. These values were higher than those reported in the literature: 3.00% by Nwabueze (2007) for raw dehulled seed flour; 3.30% for malted and 2.80% for unmalted African breadfruit seed flour by Nwabueze and Atuonwu (2007); 1.46% and 1.90% for malted and unmalted African breadfruit seed flour, respectively, by Nwabueze and Uchendu (2011); and 1.31% for raw, 1.38% for cooked, 4.96% for parboiled, and 6.79% for toasted African breadfruit seed flour by Emenonye (2016). The values obtained in this research were desirable since high fiber foods are said to benefit the heart, lower the risk of blocked arteries, heart attack, and stroke, as well as reduce appetite, thus protecting against obesity (Schill and Munz, 2011), whereas low fiber diets are not desirable since they may cause constipation and are implicated with the disease of the colon such as pile, hemorrhoids, appendicitis, and even cancer (O'Keefe, 2019). Coconut fiber stands out as more important than other fiber sources because it has no phytic acid, and so prevents the removal of minerals but increases their absorption in the body. Coconut fiber decreases the rate of emptying the stomach of foods, thereby allowing food a long time in the stomach for mineral release, and subsequent high mineral availability for body absorption (Wasserman, 2016).

Crude protein content ranged from 20.48% to 23.32% for *Ukwa* flours. The protein contents obtained in this research

TABLE 2 Proximate composition and energy values of the whole, dehulled, malted, and defatted *Ukwa* flours, maize flour, and coconut grits.

Sample	Moisture content (%)	Ash content (%)	Crude fat (%)	Crude fiber (%)	Crude protein (%)	Carbohydrate (%)	Energy value (Kcal/100 g)
WUF	3.67 ± 0.01^{e}	3.14 ± 0.14^{d}	11.24 ± 0.02^{c}	15.73 ± 0.02^{c}	20.48 ± 0.04^{e}	45.74 ± 0.01^{d}	366.48 ± 0.00^{d}
DUF	3.48 ± 0.00^{f}	3.29 ± 0.04^{c}	11.09 ± 0.01^{d}	7.77 ± 0.12^{e}	22.56 ± 0.01^{c}	52.14 ± 0.01^{b}	397.29 ± 0.03^{b}
MUF	3.76 ± 0.12^{d}	3.52 ± 0.02^{b}	11.52 ± 0.10^{b}	20.18 ± 0.10^{a}	23.32 ± 0.12^{b}	37.70 ± 0.14^{e}	305.76 ± 0.01^{f}
FUF	3.80 ± 0.02^{c}	3.07 ± 0.01^{e}	5.83 ± 0.01^{e}	19.63 ± 0.01^{b}	20.92 ± 0.01^{d}	46.75 ± 0.00^{c}	323.15 ± 0.12^{e}
WMF	3.82 ± 0.01^{b}	1.83 ± 0.12^{f}	4.79 ± 0.03^{f}	7.73 ± 0.14^{f}	9.65 ± 0.04^{f}	72.18 ± 0.01^{a}	370.43 ± 0.02^{c}
COF	4.86 ± 0.04^{a}	6.28 ± 0.01^{a}	42.12 ± 0.01^{a}	10.67 ± 0.03^{d}	27.11 ± 0.01^{a}	10.95 ± 0.02^{f}	531.41 ± 0.04^{a}

Means along the same column with different letters are significantly different at $P < 0.05$.
WUF, whole Ukwa flour; DUF, dehulled Ukwa flour; MUF, malted Ukwa flour; FUF, defatted Ukwa flour; WMF, maize flour; COF, coconut grits.

were higher compared to those reported (15.76%) by Nwabueze (2007) and 15.10%, 16.30%, and 18.00% reported by Emenonye (2016) for cooked, parboiled, and toasted African breadfruit seed flour, respectively. Maize flour showed the least crude protein content (9.65%), while the coconut grits showed the highest (27.11%). The protein content of maize flour was higher than that reported (6.9%) by Gwirtz and Garcia-Casal (2014). The difference could be due to varietal differences in the maize used. The crude protein and crude fat content of all the *Ukwa* flours could qualify them as valuable sources of nutrients. The results are in line with previous reports in the literature (Iwe and Ngoddy, 2000; Odemelam, 2000; Nwabueze, 2007; James and Nwabueze, 2013a). These results suggest that *Ukwa* could be important for a developing country like Nigeria.

The Carbohydrate content of maize flour was significantly highest (72.18%), while that of coconut grits was lowest (10.95%) among all the samples. The Carbohydrate content of *Ukwa* flours ranged from 37.70% to 52.14%, with DUF showing the highest value, while the MUF had the lowest. Activities of endogenous enzymes leading to the release of bound carbohydrates from the non-nutritive complexes of the seeds could increase the carbohydrate content of flour (Ugwu and Oranye, 2006; Emenonye, 2016). The carbohydrate contents of DUF and maize flour (WMF) were lower than those reported by Nwabueze (2007): 60.59% for dehulled raw seed flour and 73.58% for maize flour. Emenonye (2016) reported carbohydrate contents of 52.69%, 54.58%, 60.23%, and 49.30% for raw, parboiled, cooked, and toasted African breadfruit seed flours, respectively.

The energy content of flours ranged from 302.76 Kcal/100 g to 531.41 Kcal/100 g. The energy value of coconut grits (COF) was significantly higher, while that of malted *Ukwa* flour (MUF) was lower than in other samples. The amount of energy in food, required for the maintenance of basic body functions such as physical exercise, breathing, regulation of body temperature, and circulation of blood, are represented in energy value (Edima-Nyah et al., 2019).

Effect of processing treatments and levels of substitution of *Ukwa* flours on the crude protein content of maize–coconut-based snack bars

Table 3 shows the effect of treatments employed in the processing of *Ukwa* flours and the level of substitution on the protein content of maize–coconut snack bars. The protein content of snack bars ranged from 16.16% to 27.15% and increased with the increasing substituted level of *Ukwa* in the snack bar formulations. Processing increased the protein content of snack bars. The malted and the dehulled *Ukwa* snack bars showed the highest values of protein at different levels of blending interchangeably. Snack bars produced from whole *Ukwa* had the least values of protein at all levels of substitution, followed by those from defatted *Ukwa*. Significant differences ($P < 0.05$) also existed in the processing method's main effect and the composition's main effect. Processing resulted in a significant increase in the protein content of all the snack bars. The increase could be attributed to the increase in proteolytic activities and the accumulation of microbial mass. The breakdown of complex compounds, during the germinating process, into a simple form may have caused the increase. Protein increase by malting could also be a result of the solubilization of compounds in the flour and changes in the structure of storage protein (glutelins and prolamins) exposing them to enzymatic reactions (Nwabueze and Atuonwu, 2007). The increase in protein content by the defatting process could be attributed to the breakdown of protein–lipid linkages, and subsequent release of protein molecules, which eventually increases the value of crude. Proteins are important in tissue building. All the snack bar formulations show good protein content and may be regarded as a good protein source.

Analysis of variance, developed from factorial experiment, shows the effect of the model terms and the reliability of the model in modeling and predicting the crude protein response. All model terms (treatments, substitution of African breadfruit

TABLE 3 Effect of processing and substituted levels of *Ukwa* flours on crude protein content (%) of maize–coconut snack bars.

Snack bar	Processing treatments				Substitution main effect
UF:MF:CG composition	Whole	Dehulling	Malting	Defatting	
00:95:5 (control)	16.16^{t} ± 0.02	16.16^{t} ± 0.02	16.16^{t} ± 0.02	16.16^{t} ± 0.02	**16.16^{f} ± 0.01**
20:75:5	18.82^{s} ± 0.01	20.81^{n} ± 0.02	19.93^{o} ± 0.04	19.68^{p} ± 0.14	**19.81^{e} ± 0.74**
25:70:5	18.93^{r} ± 0.02	22.57^{j} ± 0.01	23.97^{g} ± 0.01	22.28^{l} ± 0.01	**21.94^{d} ± 1.93**
30:65:5	18.97^{q} ± 0.01	23.67^{h} ± 0.11	24.16^{f} ± 0.01	23.02^{i} ± 0.11	**22.45^{c} ± 2.14**
35:60:5	21.17^{m} ± 0.01	24.86^{c} ± 0.01	24.51^{d} ± 0.01	24.19^{e} ± 0.02	**23.68^{b} ± 1.53**
95:00:5	22.43^{k} ± 0.01	26.13^{b} ± 0.02	27.15^{a} ± 0.10	26.14^{b} ± 0.01	**25.46^{a} ± 1.88**
Treatment main effect	**19.43^{d} ± 2.04**	**22.37^{b} ± 3.34**	**22.65^{a} ± 3.69**	**21.91^{c} ± 3.32**	

Values are mean ± standard deviation of replicated determinations. Means with different superscripts treatment main effect row (n = 18), substitution main effect column (n = 12), and interaction cells (n = 3) are significantly ($P<0.05$) different.
UF: MF: CG, Ukwa flour: maize flour: coconut grit blend.

seed flour, and their interactions) were significant ($P < 0.05$), showing that the crude protein contents of the snack bars were significantly affected by processing, level of substitution, and their interactions. The model was significant, showing that the combination of these model terms can reliably predict the crude protein content. This is evident in the R^2 value of 1.00, which implies that 100% of the variability in the response is accounted for by the model terms. The adjusted R^2 value of 1.00 is a result of the lack of insignificant term(s) in the model, making the model accurate.

Effect of processing and substituted levels of *Ukwa* flour on *in vitro* protein digestibility of maize–coconut-based snack bars

Table 4 shows the effect of processing treatments and levels of substitution of *Ukwa* flour on the *in vitro* protein digestibility (IVPD) of snack bars. A general decrease in *in vitro* protein digestibility (IVPD) with an increase in substituted levels was observed in all *Ukwa*-based snack bars. Processing significantly ($P < 0.05$) increased the IVPD of snack bars from 63.93% to 88.34%. IVPD of snack bars produced with dehulled *Ukwa* flour recorded the highest value followed by those produced with malted, defatted, and whole *Ukwa* flour, respectively, in decreasing order. Improvement of ∼7.17% by dehulling, 5.92% by malting, and 4.30% by defatting was achieved in the IVPD of the snack bars. Alonso et al. (2000) reported an increase of IVPD in Faba and kidney beans by 2.4% and 5.14%, respectively, after dehulling. Rahim (2004) reported a change in IVPD of the SML cultivar of the Faba bean from 69.78% to 82.31% due to dehulling. Improvement of IVPD of dehulled *Ukwa*-based snack bars could be attributed to the reduction in anti-nutrients and insoluble fiber, which are found in the seed coat (hulls). High concentration of anti-nutrients and insoluble fiber in food products from cereals and legumes as protein sources results in poor protein digestibility (Gilani et al., 2005). This is probably the reason the snack bars with hulls (whole, defatted, and malted) recorded lower IVPD compared to the dehulled samples.

Malting and defatting also significantly ($P < 0.05$) increased the IVPD of snack bars. These could have been possible with reduced anti-nutrient content (Table 1), which led to subsequent improvement of IVPD (Table 4) of the snack bars, as reported by Alonso et al. (2000). Rahim (2004) reported improvement from 69.78% to 89.98% in faba beans due to germination. Yadav and Bhatnagar (2016) equally reported an improvement in IVPD from 12.50 g in control to 25.60 g in defatted soy-enriched cereal bars. Azzollini et al. (2018) reported higher values of 76% to 92% IVPD in insect-rich extruded snacks, while James and Nwabueze (2013b) recorded 70% to 72% IVPD in extruded soy snacks.

Analysis of variance of the effect of processing treatments and the levels of substitution *Ukwa* flour on the *in vitro* protein digestibility (IVPD) of snack bars showed that a significant ($P < 0.05$) main and interactive effect existed. The significant model implies that the model terms (processing treatments and substitution levels) can reliably predict the response (IVPD). The R^2 value of 1.00 and adjusted R^2 value of 1.00 show 100% variability in the response is accounted for by the model terms, without insignificant terms, making the model accurate.

Dehulling, malting, and defatting processes generally resulted in increased *in vitro* protein digestibility of the snack bars. According to Alonso et al. (2000) and Rahim (2004), the quality of food protein can be defined by the composition of amino acids and their digestibility, and the degree of digestibility would determine the number of amino acids available. This, therefore, implies that there could be increased availability of the amino acids in the snack bars when consumed.

TABLE 4 Effect of processing and substituted levels of African breadfruit seed flours on% *in vitro* protein digestibility (IVPD) of maize–coconut snack bars.

Snack bars	*In-vitro* protein digestibility (%)				Substitution main effect
UF:MF:CG composition	Whole	Dehulling	Malting	Defatting	
00:95:5	$68.19^{p} \pm 0.01$	$68.19^{p} \pm 0.01$	$68.19^{p} \pm 0.01$	$68.19^{p} \pm 0.01$	**$68.19^{e} \pm 0.01$**
20:75:5	$84.40^{d} \pm 0.01$	$88.34^{a} \pm 0.01$	$87.45^{b} \pm 0.02$	$85.85^{c} \pm 0.01$	**$86.51^{a} \pm 1.61$**
25:70:5	$72.15^{l} \pm 0.02$	$78.59^{e} \pm 0.01$	$76.33^{f} \pm 0.01$	$75.57^{g} \pm 0.01$	**$75.66^{b} \pm 2.47$**
30:65:5	$68.39^{p} \pm 0.01$	$75.21^{h} \pm 0.02$	$74.37^{i} \pm 0.02$	$73.48^{j} \pm 0.02$	**$72.86^{c} \pm 2.84$**
35:60:5	$65.82^{r} \pm 0.02$	$72.81^{k} \pm 0.01$	$72.31^{l} \pm 0.01$	$71.51^{m} \pm 0.01$	**$70.61^{d} \pm 3.01$**
95:00:5	$63.93^{s} \pm 0.01$	$70.12^{n} \pm 0.01$	$69.23^{\circ} \pm 0.01$	$66.48^{q} \pm 0.01$	**$67.44^{f} \pm 2.60$**
Treatments main effect	**$70.48^{d} \pm 7.02$**	**$75.54^{a} \pm 6.93$**	**$74.65^{b} \pm 6.65$**	**$73.51^{c} \pm 6.58$**	

Values are mean ± standard deviation of replicated determinations.
Means with different superscripts in the treatments main effect row (n = 12), substitution main effect column (n = 8), and interaction cells (n = 2) are significantly ($P < 0.05$) different.
UF:MF:CG, Ukwa flour:maize flour:coconut grit blend.

Effect of processing and substituted levels of *Ukwa* flour on *in vitro* starch digestibility of maize–coconut-based snack bars

Table 5 shows the results of the effect of processing and levels of substitution of *Ukwa* on *in vitro* starch digestibility (IVSD) of snack bars produced with maize and coconut blends. IVSD of snack bars ranged from 29.59% to 57.48%, higher than the values (11.6–13.4%) reported by Flores-Silva et al. (2015) for snacks produced with blends of chickpea, maize, and unripe plantain, while Azzollini et al. (2018) reported IVSD of 34–57% in extruded insect-rich snacks.

Processing of *Ukwa* had a significant ($P < 0.05$) effect on the IVSD of snack bars. The highest effect was achieved by dehulling, followed by malting and defatting processes in decreasing order. IVSD decreased with an increased substituted level of *Ukwa* flour in the snack bars. The reduction in *in vitro* starch digestibility due to the increase in *Ukwa* flour could probably be due to a corresponding increase in fat (lipid) content and consequently limited starch transformation. Xiaoli (2008) recorded in the literature that fat (∼5%) could reduce mechanical energy, melting temperature, prevent moisture absorption, and gelatinization by forming a hydrophobic layer around starch granules, thereby limiting the degree of starch digestibility (Altan et al., 2009).

Improvement in starch digestibility due to dehulling (up to 31%) could be a result of the reduction in fiber, phytic acid, and tannin present in the hulls, which could inhibit α-amylase activity and consequently reduce starch digestibility. Improvement of ∼29% by malting and 24% by defatting in the IVSD content of snack bars was achieved. This could be due to enzyme action in breaking down complex molecules to simpler forms and also the reduction in the anti-nutrient content of the snack bars. The reduction in anti-nutrients (such as tannins and phytic acids) is suggested to create a large space in the matrix of the food, causing an increase in enzymatic attack, and so increases the digestibility of starch (Rehman and Shah, 2005). This may explain why the snack bars from dehulled African breadfruit showed the highest starch digestibility among the snacks developed. Roopa and Premavalli (2008) in their research showed that germination among other processing methods (such as autoclaving, pressure cooking, and puffing) increased starch digestibility by 35%−40%.

Analysis of variance, developed from the factorial experiment, showed the effect of the model terms and the reliability of the model in modeling and predicting the response (*in vitro* starch digestibility). From Table 5, all model terms (treatments, substitutions of *Ukwa* flour, and interaction of the two variables) were significant ($P < 0.05$), showing that the IVSD content of snack bars was significantly affected by processing, level of substitution, and the interaction of the two independent variables. The model was significant, showing that the combination of these model terms can reliably predict the response (IVSD). This is evident in the R^2 value of 1.00, which implies that 100% of the variability in the response is accounted for by the model terms. The adjusted R^2 value of 1.00 is a result of the lack of insignificant term(s) in the model, making the model accurate.

TABLE 5 Effect of processing and substituted levels of *Ukwa* flours on the *in vitro* starch digestibility of maize–coconut snack bars.

Snack bars	*In-vitro* starch digestibility (%)				Substitution main effect
UF:MF:CG composition	Whole	Dehulling	Malting	Defatting	
0:95:5 (control)	$57.48^{a} \pm 0.00$	$57.48^{a} \pm 0.00$	$57.48^{a} \pm 0.00$	$57.48^{a} \pm 0.00$	**$57.48^{a} \pm 0.00$**
20:75:5	$48.81^{f} \pm 0.02$	$53.57^{b} \pm 0.01$	$51.70^{c} \pm 0.00$	$50.34^{d} \pm 0.01$	**$51.11^{b} \pm 1.87$**
25:70:5	$43.71^{k} \pm 0.02$	$49.32^{e} \pm 0.02$	$48.77^{f} \pm 0.01$	$47.45^{h} \pm 0.02$	**$47.31^{c} \pm 2.34$**
30:65:5	$36.05^{\circ} \pm 0.07$	$47.52^{g} \pm 0.00$	$46.54^{i} \pm 0.01$	$44.32^{j} \pm 0.02$	**$43.61^{d} \pm 4.83$**
35:60:5	$32.48^{r} \pm 0.01$	$41.61^{l} \pm 0.01$	$40.63^{m} \pm 0.02$	$40.31^{n} \pm 0.01$	**$38.76^{e} \pm 3.91$**
95:00:5	$29.59^{t} \pm 0.02$	$34.29^{p} \pm 0.01$	$31.44^{s} \pm 0.01$	$32.82^{q} \pm 0.02$	**$32.04^{f} \pm 1.85$**
Treatment main effect	**$41.35^{d} \pm 10.15$**	**$47.30^{a} \pm 7.96$**	**$46.09^{b} \pm 8.67$**	**$45.45^{c} \pm 8.09$**	

Values in this table are mean ± standard deviation of replicated determinations.
Means with different superscripts in the treatment main effect row (n = 12), substitution main effect column (n = 8), and interaction cells (n = 2) are significantly ($P < 0.05$) different.
UF:MF:CG, Ukwa flour:maize flour:coconut grit.

TABLE 6 Effects of processing and substituted levels of *Ukwa* flours on total essential amino acid (TEAA) content of maize–coconut snack bars.

Snack bar	TEAA (g/100g)				Substitution main effect
UF:MF:CG composition	Whole	Dehulling	Malting	Defatting	
0:95:5 (control)	$32.97^{m} \pm 0.00$	$32.97^{m} \pm 0.00$	$32.97^{m} \pm 0.00$	$32.97^{m} \pm 0.00$	**$32.97^{d} \pm 0.00$**
20:75:5	$30.09^{s} \pm 0.01$	$34.12^{j} \pm 0.01$	$34.29^{h} \pm 0.00$	$31.41^{q} \pm 0.01$	**$32.48^{f} \pm 1.91$**
25:70:5	$30.94^{r} \pm 0.01$	$34.11^{j} \pm 0.01$	$34.48^{g} \pm 0.01$	$32.06^{p} \pm 0.00$	**$32.90^{e} \pm 1.56$**
30:65:5	$32.48^{\circ} \pm 0.00$	$35.14^{f} \pm 0.01$	$35.97^{c} \pm 0.03$	$33.17^{l} \pm 0.04$	**$34.19^{c} \pm 1.52$**
35:60:5	$32.83^{n} \pm 0.01$	$35.71^{e} \pm 0.00$	$35.74^{d} \pm 0.01$	$33.45^{k} \pm 0.00$	**$34.43^{b} \pm 1.41$**
95:00:5	$32.46^{\circ} \pm 0.00$	$36.83^{b} \pm 0.01$	$39.05^{a} \pm 0.00$	$34.18^{i} \pm 0.00$	**$35.63^{a} \pm 2.69$**
Treatments main effect	**$31.96^{d} \pm 1.11$**	**$34.81^{b} \pm 1.30$**	**$35.42^{a} \pm 1.99$**	**$32.87^{c} \pm 0.95$**	

Values are means of replicated determinations and their standard deviation.
Means with different superscripts in the treatment main effect row (n = 12), substitution main effect column (n = 8), and interaction cells (n = 2) are significantly ($P < 0.05$) different.
UF:MF:CG, Ukwa flour:maize flour:coconut grit.

Effect of processing and substituted levels of *Ukwa* flours on total essential amino acid content of maize–coconut-based snack bars

Table 6 shows the effect of dehulling, malting, and defatting, and levels of *Ukwa* flour on the total essential amino acid (TEAA) of the snack bars from maize and coconut blends. TEAA content ranged from 30.09 g/100 g to 39.05 g/100 g of protein. Significant ($P < 0.05$) differences existed in the TEAA content of snack bars. Dehulling, malting, and defatting processes significantly ($P < 0.05$) increased the TEAA content of snack bars. Snack bars made from malted *Ukwa* flour had the highest TEAA, followed by snack bars produced with dehulled and defatted flours in decreasing order. The improvement in TEAA observed could be a result of the reduction in the anti-nutritional factors and the consequent increase in digestibility of the processed foods. The process of dehulling reduces anti-nutrients through the removal of the hull and concentrates the nutrients. Malting is said to improve the composition of essential amino acids and increase the density of nutrients (Nwabueze and Atuonwu, 2007). Increased amino acids due to malting are attributed to the solubilization of flour and changes in structures of storage protein (glutelins and prolamins), causing their availability for enzymatic attack (Alonso et al., 2000; Nwabueze and Atuonwu, 2007). The process of defatting results in the breakdown of protein–lipid complexes, releasing the protein and making them available for digestion.

ANOVA for the effect of treatments and levels of substitution of African breadfruit seed flour on the total essential amino-acid content of snack bar showed significant ($P < 0.05$) main and interactive effect existed in the treatments and substituted levels of *Ukwa* flour. Significant ($P < 0.05$) main and interactive effects existed in the treatments and substituted levels of *Ukwa* flour. The model developed from the data explained 100% variation ($R^2 = 1.00$, adjusted $R^2 = 1.00$) in the TEAA content of the snack bars.

Conclusion

The study has shown that processing treatments will reduce the anti-nutrients and increase the nutrient contents of *Ukwa*. The use of dehulled, malted, and defatted *Ukwa*, in composite with maize–coconut flour blends in the development of snack bars, showed increased availability of nutrients and increased digestibility of protein and starch. Utilization of local food crops in the production of snack bars would help in the reduction in wheat importation and consequent reduction in foreign exchange, and diversification of products thereby making available varieties to consumers. Successful application of these composite flours in snack bars production would have the potential of increasing the protein intake of the consumers of these products, increase the utilization of *Ukwa*, increase farmer's income, and thereby encourage commercial farming of these indigenous crops *Treculia africana (Ukwa),* maize, and coconut.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

AE-N: conceptualization, investigation, methodology, data curation, software analysis, writing—original draft, and writing review. PO and TN: supervision, project administration, conceptualization, investigation, methodology, data curation, software analysis, and review and editing original draft. VN and ME: writing—original draft preparation, data curation, visualization, investigation, software analysis, methodology, formal analysis, and reviewing. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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