

Effects of Different Processing Methods on the Nutritional, Phytochemical and Functional Properties of Soya bean (*Glycine max* TGX 1835-10E) commonly produced in Cameroon

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Abstract

Soya bean (variety TGX 1835-10E) is a legume commonly produced and consumed in Cameroon. Despite its affordability compared to animal sources of proteins, protein energy malnutrition (PEM) is still observed in the country and especially in rural areas. This can be attributed the way the available soya bean is processed which can easily affect its physicochemical properties and reduce its nutritional value and functional properties. This study was conducted in order to evaluate the effect of different processing methods on the nutritional composition, phytochemical and functional properties of soya bean. The beans were divided into nine groups that were processed differently and analyzed for their total phenolic content, antioxidant activity, oil quality and nutritional composition and the functional properties of their flours. Results showed that the total phenolic content was found to be ranged between 99.84 - 216.85 mg GAE/g and significantly increased with roasting and decreased with boiling treatments. All samples exhibited good antioxidant activity. All treatments altered soya bean oil quality with time. Soaking, boiling, de-hulling and drying considerably reduced the protein (43.49 to 29.93%) and carbohydrate (15.44 to 1.27%) contents of soya bean while soaking, de-hulling, boiling and drying increased its lipid content (11.60 to 15.90%). All treatments significantly reduced the mineral and anti-nutrient (phytate and oxalate) contents of soya bean. The flours exhibited good functional properties, except for emulsion and foaming capacities which significantly decrease with processing. Soya bean can be a good ingredient for food formulation and preparation, both for nutritional and technological purposes.

Keywords: soya bean, processing, nutritional composition, phytochemical property, functional property

1. Introduction

Soya bean (*Glycine max*) is one of the most nutritive legumes, cultivated annually, classified under the pea family Fabaceae and grown as an edible bean with multiple uses like soya milk, meat, flour, oil and so on (Pele *et al.*, 2016). It's widely cultivated in all parts of the world especially America, Asia and Africa (Britannica, 2019). The cultivation of soya bean in Cameroon dates as far back as 1978 (Nzossie and Bring, 2020). In present days food legumes crops have gained vital grounds in agriculture due to their good nutritive values and functional properties. The market demand of legumes keeps increasing, because they are more and more solicited by consumers and producers (Lopez-Cortez *et al.*, 2016). Soya bean production in Cameroon rose from 5,698 tons in 2001 to 24,195 tons in 2020, growing at an average annual rate of 9.23%. Since 2010, soya bean ranks second in legumes cultivated after peanut in Cameroon (Nzossie and Bring, 2020). Previous studies have depicted the nutritive values of soya bean as; 40% protein, 20% largely unsaturated fats, 17% fiber (both soluble

and insoluble) and 30% carbohydrates; also a good source of minerals such as 276 mg/100 g calcium, 280 mg/100 g magnesium, 1.797 mg/100 g potassium, 16 mg/100 g iron and 4.8 mg/100 g zinc, making it a total of 5% minerals and ash (Mateos-Aparicio *et al.*, 2008; Carrera *et al.*, 2011). According to Fabiyi and Hamidu (2011), soya bean has very good quality proteins, comparable to those of meat and milk, despite the fact that it is limited in some amino acids such as methionine and cysteine. Apart from these nutrients, soya bean is rich in natural antioxidants; mainly phenolic compounds amongst which the most represented classes are phenolic acids and flavonoids. Amongst these compounds, isoflavones are the most abundant with recognized health benefits (Hendrich and Murphy, 2001; Lee *et al.*, 2011). Raw soya bean contains significant amounts of antinutrients such as trypsin inhibitors, saponins, gums, phytic acid etc which block the bioavailability of some nutrients and can lead to health issues if consumed in high concentration. However, most of these antinutritional factors are eliminated during processing (Mikic *et al.*, 2009; Sharma *et al.*, 2011). Soya bean is not cooked and consumed like the other beans. In Cameroon, it is processed into flour, yoghurt, milk, oil, meat and paste (for the preparation of soya bean sauce).

The most recurrent form of malnutrition that affects the world's population with significant effect in developing countries is under-nutrition. This form of malnutrition has huge impact on human health and consequently reduces the intellectual capacity and productivity of the people suffering from it, not forgetting the impact on the socio-economic development of nations at large and communities in particular (Fanzo, 2012). From WHO statistics, the number of undernourished people in sub Saharan Africa rose from 121 million in 2010 to 222 million in 2019; with the impacted number of children rising from 50.6 to 58.7 million as a result of population evolution (WHO, 2019). As far as the children are concerned, their major cause of morbidity and mortality in Africa is protein-energy malnutrition. This is generally associated with the fact that the cost of other protein sources such as fish, meat, poultry etc is too high for a majority of the population who are poor (Tiencheu and Womeni, 2017). There is therefore an increasing demand for protein rich foods in developing countries taking into consideration their low cost, availability and accessibility to the population (Jaynie, 2018). As alternative to animal source proteins, there are legumes such as soya bean that were proven to have good quality proteins (Fabiyi and Hamidu, 2011). Soya bean was also demonstrated as an alternative source of milk for people who are lactose intolerant. Added to this, its good content in isoflavones makes it to have good phytochemical properties (Hendrich and Murphy, 2001). In Cameroon, soya bean is highly solicited as the main and most used vegetable protein, in addition to the fact that their production requires low capital investment (Pele *et al.*, 2016). Despite these advantages, protein-energy malnutrition is still a challenge. It is important to emphasize on the fact that the way foods are processed significantly impact the retention of their nutrients, antinutrients and bioactives as well as the functional properties of the food sample. It is well known that ignorance is one of the major causes of malnutrition (Womeni *et al.*, 2012; Uboh *et al.*, 2014; Djikeng *et al.*, 2017; Iwanegbe *et al.*, 2018). There is a need to inform the population and educate them on the good processing methods that better preserve the nutritional, functional and organoleptic properties of selected food samples. Soya bean is generally used as complement in the formulation of infant formulae which are still not accessible by poor people or those living in rural areas. Locally, the soya bean is roasted, ground and added to infant pap or cereal blends. In households, the processing methods generally applied on soya bean before consumption are roasting, boiling, soaking, drying, extrusion, salt treatment, fermentation, germination, urea treatment etc (Akande and Fabiyi, 2010). Extreme processing of foods at high temperature can lead to chemical alteration reactions such as lipid oxidation and non-enzymatic browning reactions which can have deleterious effects on nutrient and bioactive retention (Djikeng *et al.*, 2017, 2018). Lipid oxidation and non-enzymatic browning reactions can lead to the drop in the nutritional properties of the food samples by causing a loss of essential amino acids, essential fatty acids, vitamins, available carbohydrates as well as a reduction of protein digestibility. The organoleptic characteristics of the food sample can also be affected (Cuvelier and Maillard, 2012). Processing methods can have a significant impact on the nutritional and phytochemical composition of soya bean.

In previous studies, the impact of hot and cold processing methods on the phytochemical, nutritional and functional properties of food, especially legumes was reported. Pele *et al.* (2016) evaluated the effect of soaking, sun-drying and milling, soaking and de-hulling and sprouting on the nutritional and antinutritional properties of soya bean. In the same line, the influence of boiling (30 min), germination, cooking with NaCO₃, autoclaving and dehulling on the chemical qualities and functional properties of soy flour was investigated by Ukwuru (2003). The nutritional composition and functional properties of bean flour from 3 soya bean varieties from Ghana was reported by Eshun (2012). The changes in phenolic compounds and antioxidant properties of high protein soya bean for different roasting conditions were evaluated by Lee *et al.* (2013). In other studies, the effect of processing techniques on the bioactive content and antioxidant activity of other legumes such as foxtail millet, broad beans were stated (Saini *et al.*, 2016; Zhang *et al.*, 2017). Woumbo *et al.* (2017) tested the impact

of roasting, sprouting and boiling on the phytochemical composition and anti-obesity potential of soya bean in rats. Though several investigations have been carried out on the effect of processing methods on the nutritional, functional and phytochemical properties of soya bean, there is however very limited information on the impact of local processing techniques (boiling, soaking, traditional and oven roasting) applied in Cameroon on the nutritional composition, phytochemical and functional properties of soya bean varieties available in the country. The objective of this study was to evaluate the influence of different processing methods on the nutritional composition, phytochemical and functional properties of soya bean.

2. Materials and Methods

2.1 Materials

Soya beans (*Glycine max*), TGX 1835-10E variety was harvested at the dry stage from the experimental farm of the Institute of Agricultural Research for Development (IRAD), Foumbot Multipurpose Station, West region of Cameroon in December 2021.

The chemicals and reagents used in this study were of analytical grade.

2.2 Methods

2.2.1 Sample Preparation

Soya beans (15 Kg) was taken to the laboratory where after cleaning; it was divided into nine (09) different groups.

- ❖ Group 1 (600 g) was untreated soya bean (Raw) and served as control (Control 1). It was coded USB
- ❖ Group 2 (600 g) was soaked, de-hulled and dried and served as second control (Control 2). It was given the code SDSB
- ❖ Group 3 (1200 g) was divided into two sub-groups that were soaked in water for 24 h, de-hulled and boiled (~98°C) in 5 L of tap water at two different times, 20 and 40 min respectively, before being dried in the oven at 50 °C for 24 hours. They were respectively attributed the codes SDBDSB_{20 min} and SDBDSB_{40 min}
- ❖ Group 4 (1200 g) was divided into two sub-groups that were soaked in water for 24 h, de-hulled and dried in the oven at 50 °C for 24 hours before being pot roasted (250 - 290 °C) at two different times, 10 and 20 min respectively. They were respectively coded SDDPRSB_{10 min} and SDDPRSB_{20 min}
- ❖ Group 5 (1200 g) was divided into two sub-groups that were soaked in water for 24 h, de-hulled and dried in the oven at 50 °C before being oven roasted (250 - 290 °C) at two different times, 10 and 20 min respectively. They were respectively coded SDDORSB_{T1}, SDDORSB_{10 min} and SDDORSB_{20 min}
- ❖ Group 6 (1200 g) was divided into two sub-groups that were soaked in water for 24 h and boiled (~98°C) in 5 L of tap water at two different times, 10 and 20 min respectively. After de-hulling, they were dried in the oven at 50 °C for 24 hours. They were respectively coded SBDDSB_{10 min}, and SBDDSB_{20 min}
- ❖ Group 7 (1200 g) was divided into two sub-groups that were directly boiled (~98°C) in 5 L of tap water at two different times, 20 and 40 min respectively, de-hulled before being dried in the oven at 50 °C. They were respectively coded BDDSB_{20 min} and BDDSB_{40 min}.
- ❖ Group 8 (1200 g) was divided into two sub-groups that were oven roasted (250 - 290 °C) at two different times, 15 and 30 min respectively. They were respectively coded ORSB_{15 min}, and ORSB_{30 min}
- ❖ Group 9 (1200 g) was divided into two sub-groups that were pot roasted using (250 - 290 °C) at two different times, 15 and 30 min. They were respectively coded PRSB_{15 min} and PRSB_{30 min}.

All samples were ground to powder to pass through a 1 mm diameter sieve for analysis.

2.2.2 Extraction of Bioactives and Soya Bean Oil

2.2.2.1 Extraction of Phenolic Compounds

Phenolic antioxidants were extracted from soya bean samples using the maceration method as described by Womeni *et al.* (2016). Fifty (50 g) grams flour was soaked in 200 ml of methanol at about 25°C for 48 hours. The sample was regularly stirred for 24 hours and the mixture filtered using the Whatman paper (No 1). The solid residue was again soaked in 100 ml of methanol to maximize the extraction of phenolic antioxidants and under similar conditions. After filtration, the filtrate was collected and mixed with the previous one before being evaporated on a rotatory evaporator at 40 °C under vacuum for the removal of the solvent. The dehydrated extract was weighted to estimate the extraction yield and stored in the freezer for subsequent analysis.

2.2.2.2 Extraction of the Oil

Soya bean oil was extracted using the method described by Womeni *et al.* (2013). About 200 g of flour was

soaked in 800 ml of hexane for 48 hours with regular stirring. The mixture was filtrated using Whatman paper No 1 and the solid residue re-extracted under similar conditions but using 400 ml of solvent. The obtained filtrated were mixed and solvent removed by evaporation at 40 °C under vacuum using a rotatory evaporator. The oil was then weighted to calculate the mean based on the amount of flour used before being stored in the freezer for further analysis.

2.2.3 Determination of the Total Phenolic Content

The impact of the different processing methods, on the total phenolic content of soya bean was accessed using the Folin-Ciocalteu method, as described by Gao *et al.* (2000). About 20 µl of a 2000 µg/l of extract was added into a 5 ml test tube followed by the addition of 0.2 ml of Folin-Ciocalteu reagent and 2 ml of distilled water. The sample was incubated at room temperature for 3 min and 1 ml of 20% sodium carbonate added. After that, the mixture was again incubated for 20 min under similar conditions as previously mentioned. The absorbance of the final solution was recorded at 765 nm using a spectrophotometer. The amount of phenolic compound present in each extract was calculated from the gallic acid standard curve and expressed as milligrams equivalents gallic acid per gram of extract (mg GAE/g).

2.2.4 Effect of Different Processing Methods on the Quality of Soya Bean Oil

2.2.4.1 Peroxide Value

The IDF standard method 74A: 1991 (1991) was used for the determination of the peroxide value of the extracted oil samples. About 0.01-0.05 g of oil was weighted into a 15 ml test tube. After that, 9.8 ml of the mixture chloroform-methanol (7:3 v/v) was added and the mixture stirred for 2-4 seconds using a vortex. After that, 50 µl of a 30% ammonium thiocyanate solution was added, followed by 50 µl of iron (II) solution. The mixture was stirred for 2-4 seconds before being incubated at room temperature (~25 °C) for 5 min and the absorbance recorded at 500 nm. The experiment was conducted under soft light and lasted for 10 min. The peroxide value was calculated as followed using iron (III) chloride standard curve (10 µg Fe/ml):

$$PV = \frac{(As - Ab) \times m}{55.84 \times m_0 \times 2}$$

Where As = absorbance of the sample; Ab = absorbance of the blank; m = slope, obtained from the calibration curve (in this experiment 38.40); m₀ = mass in grams of the sample; 55.84 = atomic weight of iron.

2.2.4.2 Thiobarbituric Acid Value

The method described by Draper and Hadley (1990) was used for the determination of the thiobarbituric acid value. About 0.1-0.2 g of oil sample was weighted and introduced in a 5 ml test tube. After that, 1 ml of a 0.1% trichloroacetic acid aqueous solution was added. After vigorous stirring on a vortex, 1 ml of a 0.375% aqueous solution of 2-thiobarbituric acid was added. The solution was stirred again and 1 ml of 15% trichloroacetic acid and 1 ml of 0.25 N hydrochloric acid were added. The solution was stirred again and incubated for 30 min in a water bath until the pink colour appears. After cooling the solution down and centrifuging it at 4500 g, the absorbance of the supernatant was recorded at 500 nm against the blank. The thiobarbituric acid value expressed as mg MDA/Kg sample was evaluated using the formula:

$$TBA \text{ value} = \frac{(As \times V_{TCA} \times 2 \times M \times 10^{-2})}{1.56 \times m}$$

Where, As = corrected absorbance; V_{TCA} = total volume of TCA; M = Molecular weight of malondialdehyde (72 g/mol); m = sample weight.

2.2.4.3 Acid Value

The AOCS method (2003) was used for the determination of the acid value. About 1 g of oil sample was introduced in a 250 ml Erlenmeyer flask followed by 100 ml of methanol 95%. After that, two drops of phenolphthalein 1% was added and the mixture titrated using a 0.1 N KOH solution prepared in methanol. The volume of KOH (V₁ and V₀) consumed to reach the end-point (pink colour persisting for 10 s) for both sample and blank were recorded and used for the calculation of the acid value using the formula:

$$AV = \frac{(V_1 - V_0) \times 56.1 \times T}{m}$$

Where,

AV = Acid value

V_o (ml) : Volume KOH solution for the blanc

V (ml) : Volume KOH solution for the sample

T : Concentration of the KOH solution

m (g) : Mass of sample

The acidity in oleic acid percent was calculated following the formula:

$$AV (\% \text{ Oleic acid}) = \frac{AV \times 282 \times 100}{56.1 \times 1000}$$

2.2.5 Determination of the Influence of Different Processing Methods on some Nutrients and Anti-nutrient Content of Soya Bean

2.2.5.1 Proximate Composition

The methods described by Association of Official Analytical Chemists (1990) were used for the analysis of the proximate composition. The parameters analyzed were protein, fat, ash, moisture and carbohydrate contents. For the moisture content, samples were dehydrated in an electric air-dried oven at 103 °C till constant weight. The ash content was obtained by incinerating the samples at 550 °C following the AOAC procedure 942.05. The nitrogen content was determined using the micro-Kjeldahl method according to the AOAC procedure 984.13 and the protein estimated as nitrogen x 6.25. The soxhlet method was used for the determination of the lipid content following the AOAC procedure 963.15. For the fiber content, the AOAC (2005) method was used. The amount of carbohydrates was obtained by difference (AOAC, 1990) after deducting the lipid, moisture, protein, fiber and ash contents from 100.

2.2.5.2 Mineral Content

The ash from each sample was dissolved with 10 ml of a 20% HCl solution. After filtration, the filtrate was used for mineral identification and quantification. An atomic absorption spectrometer (Varian 220FS Spectra AA, Les Ulis, France) was used for the determination of the calcium, sodium, iron, potassium and magnesium contents. Phosphorus was obtained using the vanadomolybdate colorimetric method. Calibration curves of standards were used for this purpose.

2.2.6 Antinutrients

2.2.6.1 Oxalate

The method of Naik *et al.* (2014) with slight modifications was used to determine the oxalate content in soya bean flour samples. About 0.25 g of sample was introduced in a beaker and 15 ml of a 0.25 N HCl solution was added. The mixture was incubated in the water bath for 15 min at 98 °C before being cooled filtered and the volume of supernatant measured. To 0.5 ml of supernatant, 2.5 ml of a 2 N sulfuric acid solution and 1ml of a 0.003 M potassium permanganate solution were added. The solution was incubated at room temperature for 10 min and the absorbance read against a blank at 528 nm. The amount of oxalate was calculated using calcium oxalate (5 mg/ml) as standard.

2.2.6.2 Phytate

The method described by Vantraub and Lapteva (1988) was used for the determination of the phytate content. About 2 g of soyabean flour was extracted with 20 ml HCl solution (2.4%) under constant stirring for 1 hour and at room temperature. After filtration, 1.8 ml of the supernatant was collected and introduced into a 5 ml test tube. To this aliquot was added 1.2 ml of wade reagent (0.03% solution of FeCl₃.6H₂O and 0.3% of sulfosalicylic acid in water).The mixture was stirred for 5 seconds and the absorbance recorded at 500 nm using a spectrophotometer. The phytic acid content was calculated from the calibration curve using sodium phytate (5 mg/ml) as standard.

2.2.6.3 Tannins

The tannin content was determined using the method reported by Bainbridge *et al.* (1996). About 0.5 g of soya bean flour was soaked with 30 ml methanol 70%. After extracting for 30 min under constant stirring, the solution was filtered using the Whatman paper No 1. The extraction was done in duplicate. The obtained filtrate was

completed to 100 ml with distilled water. The standard solution made-up of tannic acid (0.1 mg/ml) was prepared in methanol 98%. To 1 ml of extract solution was added 5 ml of vanillin reagent. After 20 min of incubation, the absorbance was measured against a blank. The tannin content was calculated from the calibration curve.

2.2.7 Impact of Processing on the Functional Properties of Non-defatted and Defatted Soya Bean Flour

2.2.7.1 Water Absorption (WHC) and Oil Absorption Capacity (OHC)

These parameters were determined using the method described by Lin *et al.* (1974) modified by Tambo *et al.* (2019). About 1 gram of non-defatted or defatted soya bean flour was respectively mixed with 10 ml of soya bean oil or distilled water and incubated in a water bath at 30 °C for 30 min. The mixture was centrifuged at 4,500 g for 15 min. The volume of water or oil absorbed was measured. The WHC and OHC were calculated as follows:

$$\text{WAC/OAC} = \frac{v_i - v_f}{v_i} \times 100$$

Where: v_i = Initial volume of water/oil, v_f = volume of water/oil after centrifugation.

2.2.7.2 Swelling Capacity (SC)

The swelling capacity of non-defatted and defatted soya bean flours was determined according to the method described by Okezie and Bello (1988) modified by Tambo *et al.* (2019). Soya bean flours solutions (10%) (w/v) were prepared in distilled water and incubated in the water bath for 30 min at 30 °C. The mixture was centrifuged at 4,500 g for 15 min. The swelling capacity (SC) was calculated as the difference between the weight of the sample that has retained the water (W_1) and that of the initial sample (W_0). The SC was calculated using the following equation:

$$\text{SC} = \frac{[(W_1 - W_0) \times 100]}{W_1}$$

2.2.7.3 Emulsion Activity and Stability (EA)

The emulsion activity (EA) was determined according to the method of Beuchat (1977) while their stability was evaluated as described by Kinsella (1979). About 1g of each non-defatted and defatted soya bean flour was mixed with 3 ml of distilled water and 3 ml of refined palm olein in graduated centrifugation tubes. The mixture was stirred for 10 min using a vortex and centrifuged at 3,500 g for 30 min and the emulsion's height measured. For emulsion stability (ES), the tubes were first heated at 80 °C for 30 min before the centrifugation process. EA and ES were calculated as presented below:

$$\text{AE} (\%) = \text{He}/\text{Hw} \times 100$$

$$\text{ES} (\%) = \text{Hes}/\text{Hws} \times 100$$

Where: He = Height of the emulsified layer in cm; Hw = Total height of the liquid in the tube in cm; Hes = Height of the emulsified layer after treatment (in cm); Hws = Total height of the liquid in the tube after thermal treatment in cm

2.2.7.4 Loose and Packed Bulk Densities

About 20 g of soya bean flour (defatted or non-defatted) was introduced into a 100 ml measuring cylinder and the volume occupied by the sample noted. After that, the sample was tapped 100 times, and the volume recorded. The loose and packed densities calculated as follow (Okaka and Okorie, 1991):

$$\text{Loose density, Packed density} = \text{Weight of Sample}/\text{Volume occupied by the sample}$$

2.2.7.5 Hausner Ratio and Porosity

Hausner ratio and porosity of the non-defatted and defatted flours were determined using the formula:

$$\text{Hausner ratio} = \text{Packed density}/\text{Loose density}$$

$$\text{Porosity} = (\text{Packed density} - \text{Loose density}/\text{Packed density}) \times 100$$

2.2.7.6 pH

The pH was measured as described by AOAC (1990). About 1 g of each sample was transferred in centrifugation tubes and 10 ml of distilled water was added. The obtained mixture was stirred for 30 min on a vortex and centrifuged at 4,500 g for 15 min. The pH of the aqueous phase was measured using a calibrated pH-meter at

about 25 °C.

2.2.7.7 Foaming Capacity

This parameter was determined as reported by Onwuka (2005). About 2 g of defatted and non-defatted soya bean flour was mixed with 50 mL of distilled water in a 100 mL measuring cylinder. The suspension was stirred to foam and the total volume after 30 s recorded. The percentage increase in volume after 30 s was expressed as foaming capacity using the formula:

$$\text{Foaming capacity (\%)} = \frac{\text{Volume after whipping} - \text{Volume before whipping}}{\text{Volume after whipping}} \times 100$$

2.2.7.8 Protein Solubility

Defatted and Non-defatted soya bean flour samples were analyzed for their protein solubility according to the method described by Ige *et al.* (1984). About 1 g of sample was dissolved in 25 mL of distilled water and the pH adjusted to the desired value using a 1 N HCl/NaOH solutions. The pH range 1-12 was considered. The tubes containing the samples were centrifuged at 4,000 g for 15 min and protein content determined using the biuret method (Gornal *et al.*, 1949). Protein solubility was calculated using the following formula:

$$\text{Solubility(\%)} = \frac{M_1}{M_2} \times 100$$

Where: M_1 = Mass of protein in the supernatant (g)

M_2 = Mass of sample (g).

2.2.8 Statistical Analysis

Analysis was done in triplicate for the determination of the total phenolic content and antioxidant activity and in duplicate for the evaluation of the nutritional value, and anti-nutritional factor, oil quality and for the functional properties. The data were subjected to one way analysis of variance (ANOVA) depending on the factors to be compared. The Student-Newman-Keuls tests of Graphpad-InStat version 3.05 and Statgraphics Centurion version XVI were used to evaluate the statistical significance of the data. A probability value at $p < 0.05$ was statistically significant.

3. Results and Discussion

3.1 Extraction Yields and Total Phenolic Content

3.1.1 Extraction Yield

The variations in extraction yields for the oil and extract are presented in Table 1. The oil yield was found to be ranged between 3.16 - 7.14% while, the methanolic extract yield was ranged between 4.91 - 9.07%. The oil yield obtained in this study was significantly lower compared to 18.3% reported by Womeni *et al.* (2013) with soya bean using the same method. The extraction yield for the methanolic extract was close to 5 - 11% obtained by Lee *et al.* (2015) with brown soya bean and with ethanol 95% and 75% respectively. These variations can be attributed to the nature of the solvent used, the availability of extractable substances, climatic conditions, and the nature of the soil as reported by Hsu *et al.* (2006).

3.1.2 Total Phenolic Content (TPC)

Phenolic compounds are one of the major secondary metabolites found in plants which are classified into phenolic acid, flavonoids and polyphenols. They have been proven to be endowed with beneficial properties for humans such as the prevention of cardiovascular diseases, cancers etc that may be largely ascribed to their powerful antioxidant activity against reactive oxygen species produced by the oxidative stress (Panzella, 2020; Lim, 2012). The changes in total phenolic content (TPC) of soya bean during processing are presented in Table 1. Results showed that it was ranged between 99.84 - 216.85 mg GAE/g which was significantly higher than 10 - 14 mg GAE/g reported by Woumbo *et al.* (2017) and 548 mg GAE/100g obtained by Guzmán-Ortiz *et al.* (2017). The differences observed can be attributed to environmental variations (temperature, climate, location, pest exposure, the solvent and determination methods used as reported by Kim and Choe (2004) and Shan *et al.* (2005).

Table 1. Extraction yields and total phenolic content

Samples	Total Phenolic Content (mg GAE/g)	Extraction Yield (%)	Oil Extraction Yield (%)
USB (Control 1)	139.77±4.51 ^c	8.39	3.28
SDSB (Control 2)	137.38±2.25 ^c	9.71	4.28
SDBDSB 20 min	163.73±0.00 ^e	4.91	4.5
SDBDSB 40 min	132.98±1.69 ^c	5.34	4.2
SDDPRSB 10 min	179.71±0.00 ^g ^h	9.07	4.04
SDDPRSB 20 min	191.69±2.25 ^h	5.10	4.92
SDDORSB 10 min	166.13±4.51 ^{ef}	8.90	4.68
SDDORSB 20 min	182.90±0.00 ^g ^h	7.70	4.64
SBDDSB 20 min	125.39±0.00 ^b	3.89	4.2
SBDDSB 40 min	99.84±0.00 ^a	5.10	4.24
BDDSB 20 min	172.92±5.08 ^f ^g	7.12	4.6
BDDSB 40 min	125.79±7.34 ^b	5.62	7.14
ORSB 15 min	153.75±9.60 ^d	7.06	6.42
ORSB 30 min	216.85±9.60 ⁱ	6.33	3.74
PRSB 15 min	137.77±7.34 ^c	6.58	3.48
PRSB 30 min	267.17±14.11 ^j	6.56	3.16

n=3. Values for the total phenolic content are presented as mean ± standard deviation. ^(a-i) values of the same column with different superscripts are significantly different at p<0.05. **USB (Control 1)**: Untreated Soya bean; **SDSB (Control 2)**: Soaked, De-hulled and Dried Soya bean; **SDBDSB 20 min**: Soaked, De-hulled, Boiled for 20 min and Dried Soya bean; **SDBDSB 40 min**: Soaked, De-hulled, Boiled for 40 min and Dried Soya bean; **SDDPRSB 10 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 10 min; **SDDPRSB 20 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 20 min; **SDDORSB 10 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 10 min; **SDDORSB 20 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 20 min; **SBDDSB 20 min**: Soaked, Boiled for 20 min, De-hulled, and Dried Soya bean; **SBDDSB 40 min**: Soaked, Boiled for 40 min, De-hulled, and Dried Soya bean; **BDDSB 20 min**: Boiled for 20 min, De-hulled and Dried Soya bean; **BDDSB 40 min**: Boiled for 40 min, De-hulled and Dried Soya bean; **ORSB 15 min**: Oven Roasted Soya bean for 15 min; **ORSB 30 min**: Oven Roasted Soya bean for 30 min; **PRSB 15 min**: Pot Roasted Soya bean for 15 min; **PRSB 30 min**: Pot Roasted Soya bean for 30 min.

Results also showed that some treatments such as SDDPRSB, SDDORSB and PRSB significantly (p<0.05) increased the total phenolic content of soya bean. This can be due to the polymerization and oxidation of some phenolic compounds or to the release of the bound molecules (Guzman-Ortiz *et al.*, 2017). Similar observations were made by Djikeng *et al.* (2022) and Lee *et al.* (2013) during roasting of tigernuts and high protein soya bean respectively. On the other hand, SDBDSB, SBDDSB and BDDSB considerably reduced the TPC of soya bean. This reduction can be attributed to the leaching of phenolic antioxidants into the boiling water or to the thermal decomposition of some of them. This result is in agreement with those of Djikeng *et al.* (2022) which showed that boiling significantly reduced the TPC of tigernuts (Azad *et al.*, 2019; Vaher *et al.*, 2010; Manzocco *et al.*, 2000).

3.2 Changes in Soya Bean Oil Quality, Proximate Composition, Mineral and Antinutrient Contents during Processing

3.2.1 Soya Bean Oil Quality

The variations in soya bean oil quality during processing are presented in Table 2. It can be observed that the peroxide value, thiobarbituric acid value and acid value ranged between 10.57 - 37.43 meq O₂/Kg, 7.02 - 25.96 ppm and 2.09 - 31.77% oleic acid respectively.

The analysis of the peroxide value of oil informs on its primary oxidation state marked by the production of hydroperoxides (Djikeng *et al.*, 2017). The output of the evaluation of this parameter showed that almost all samples had a PV higher (p<0.05) than 15 meq O₂/kg which is the highest peroxide value for good quality crude oils (FAO and WHO, 2009). This can be explained by their high concentration in hydroperoxide which can be the consequence of the treatments received by the crop. The results showed that the following processing

methods, PRSB, ORSB, and SBDDSB significantly ($p < 0.05$) increased the peroxide value of soya bean oil. These treatments might favor the formation and accumulation of hydroperoxides which are catalyzed by the heat. Similar results were obtained by Djikeng *et al.* (2017) during processing (boiling and roasting) of walnut seeds. The significant decrease in peroxide values registered in some samples can be attributed to the decomposition of hydroperoxides into secondary oxidation products such as aldehydes, ketones etc. (Womeni *et al.*, 2016).

The determination of the thiobarbituric acid value of oil, informs on its secondary oxidation state which is characterized by the presence of malondialdehyde (Iqbal and Bhangar, 2007). The result exhibited a significant ($p < 0.05$) increase in this parameter in almost all samples compared to the control. This is the proof of the presence in considerable amount of malondialdehydes produced from the breakdown of hydroperoxides under the influence of heat (Womeni *et al.*, 2016). These results are in accordance with those of Tenyang *et al.* (2021) and Djikeng *et al.* (2022) who reported that, the amount of secondary oxidation products in sesame and tigernut oils significantly increased during thermal treatments.

The determination of acid value helps to have an idea on the acidity of edible oils and fats which is generally the consequence of the presence of free fatty acids released by the decomposition of triacylglycerol due to high temperature or enzymes (Tynek *et al.*, 2001). The analysis of results presented in Table 2 showed a significant ($p < 0.05$) increase in acid value for SDBDSB, SBDDSB and BDDSB 20 min. This might be due to the thermal decomposition of triglycerides through hydrolysis reactions. Generally, the majority of the samples presented an acidity similar or lower than 4 mg KOH/g which is the standard acid value for crude oils (FAO and WHO, 2009). The fact that some thermal treatments can significantly increase the acidity of oils and fats has already been reported (Djikeng *et al.*, 2022; Iqbal and Bhangar, 2007; Tenyang *et al.*, 2021).

Table 2. Variations in soya bean oil quality during processing

Samples	Peroxide Value (meq O ₂ /kg)	Thiobarbituric Acid (ppm)	Acid Value (% oleic acid)
USB (Control 1)	18.40±0.01 ^c	7.02±0.09 ^a	4.35±0.33 ^{ab}
SDSB (Control 2)	20.31±0.25 ^c	8.21±0.30 ^{ab}	2.09±0.10 ^a
SDBDSB 20 min	18.35±0.00 ^c	19.38±2.36 ^{fg}	4.33±0.00 ^a ^b
SDBDSB 40 min	15.30±0.02 ^b	15.48±1.46 ^{def}	21.29±3.23 ^d
SDDPRSB 10 min	10.57±0.06 ^a	9.11±1.18 ^{abc}	3.93±0.57 ^{ab}
SDDPRSB 20 min	27.69±0.10 ^d	10.62±1.39 ^{abcd}	3.93±0.57 ^{ab}
SDDORSB 10 min	33.41±0.00 ^e	12.52±1.08 ^{bcde}	3.68±0.22 ^{ab}
SDDORSB 20 min	19.97±2.50 ^c	11.72±2.03 ^{abcd}	2.09±0.10 ^a
SBDDSB 20 min	37.43±1.01 ^e	24.70±1.12 ^g	2.17±0.16 ^a
SBDDSB 40 min	19.69±0.00 ^c	25.96±5.61 ^g	10.09±1.74 ^c
BDDSB 20 min	10.88±1.16 ^a	16.94±0.83 ^{ef}	31.77±1.06 ^e
BDDSB 40 min	19.33±3.06 ^c	12.85±1.00 ^{bcde}	5.93±0.99 ^b
ORSB 15 min	20.39±1.02 ^c	13.59±2.45 ^{cde}	5.37±1.46 ^{ab}
ORSB 30 min	27.21±0.20 ^d	15.62±1.56 ^{def}	4.51±0.25 ^{ab}
PRSB 15 min	18.49±2.20 ^c	17.42±1.55 ^{ef}	2.35±1.47 ^a
PRSB 30 min	33.72±0.70 ^e	22.42±1.35 ^g	4.18±0.21 ^{ab}

n=3. Values are presented as mean ± standard deviation. ^(a-k) values of the same column with different superscripts are significantly different at $p < 0.05$. **USB (Control 1):** Untreated Soya bean; **SDSB (Control 2):** Soaked, De-hulled and Dried Soya bean; **SDBDSB 20 min:** Soaked, De-hulled, Boiled for 20 min and Dried Soya bean; **SDBDSB 40 min:** Soaked, De-hulled, Boiled for 40 min and Dried Soya bean; **SDDPRSB 10 min:** Soaked, De-hulled, Dried and Pot Roasted Soya bean for 10 min; **SDDPRSB 20 min:** Soaked, De-hulled, Dried and Pot Roasted Soya bean for 20 min; **SDDORSB 10 min:** Soaked, De-hulled, Dried and Oven Roasted Soya bean for 10 min; **SDDORSB 20 min:** Soaked, De-hulled, Dried and Oven Roasted Soya bean for 20 min; **SBDDSB 20 min:** Soaked, Boiled for 20 min, De-hulled, and Dried Soya bean; **SBDDSB 40 min:** Soaked, Boiled for 40 min, De-hulled, and Dried Soya bean; **BDDSB 20 min:** Boiled for 20 min, De-hulled and Dried Soya bean; **BDDSB 40 min:** Boiled for 40 min, De-hulled and Dried Soya bean; **ORSB 15 min:** Oven Roasted Soya bean for 15 min; **ORSB 30 min:** Oven Roasted Soya bean for 30 min; **PRSB 15 min:** Pot Roasted Soya bean for 15 min; **PRSB 30 min:** Pot Roasted Soya bean for 30 min.

3.2.2 Proximate Composition

The influence of different processing methods on the proximate composition of soya bean is presented in Table 3. The outputs revealed a significant ($p < 0.05$) decrease in moisture content in all processed samples compared to the control. The significantly lower moisture content observed in treated samples reflects their good stability. Knowing this parameter gives an idea of the shelf-life of a specific food product. Samples with important moisture content are generally susceptible to physicochemical and microbial alterations (Ashworth and Draper, 1992). The moisture content in this study was ranged between 0.50 - 8.16% which is close to 5.1 - 8.8% reported by Agume *et al.* (2017) but in general lower than 8.52 - 9.15% obtained by Suryana *et al.* (2022). The dry matter (91.83 - 99.50%) was not far from 83.80 - 95.96% revealed by Maidala *et al.* (2013).

Table 3. Changes in proximate composition of soya bean during processing

Samples	Dry matter (%)	Moisture (%)	Lipid (%)	Protein (%)	Ash (%)	Fiber (%)	Carbohydrate (%)	Energy (Kcal)
USB (Control 1)	91.83±0.29 ^a	8.16±0.29 ^g	11.60±0.70 ^c	35.18±0.57 ^{bc}	4.00±0.10 ^b	5.58±0.12 ^d	5.84±0.00 ^b	268.48
SDSB (Control 2)	96.49±0.01 ^{cd}	3.50±0.01 ^{de}	12.38±0.55 ^{cd}	38.24±1.10 ^c	3.00±0.01 ^a	6.84±0.10 ^g	12.52±0.25 ^{de}	314.46
SDBDSB 20 min	96.28±1.13 ^{bcd}	3.71±1.13 ^{def}	15.30±0.27 ^{gh}	42.61±0.06 ^{cd}	4.00±0.01 ^b	4.85±0.06 ^b	14.75±0.10 ^{fg}	367.14
SDBDSB 40 min	97.04±0.69 ^{de}	2.95±0.69 ^{cd}	15.90±0.17 ^h	41.74±0.27 ^{cd}	4.00±0.12 ^b	5.71±0.00 ^d	13.18±0.27 ^d	362.78
SDDPRSB 10 min	98.28±1.04 ^{efg}	1.71±1.04 ^{abc}	12.83±0.32 ^{de}	43.05±2.55 ^{cd}	5.00±0.03 ^c	6.92±0.21 ^e	16.59±0.56 ^e	354.03
SDDPRSB 20 min	99.50±0.70 ^g	0.50±0.00 ^a	12.23±0.27 ^{cd}	38.68±2.07 ^{cd}	4.00±0.00 ^b	6.03±0.00 ^{ef}	15.92±0.71 ^{fg}	328.47
SDDORSB 10 min	97.97±0.01 ^{ef}	2.02±0.01 ^{bc}	11.98±0.38 ^{cd}	43.05±1.10 ^{cd}	4.00±0.00 ^b	5.97±0.03 ^e	19.08±1.23 ^h	356.34
SDDORSB 20 min	98.03±0.69 ^{efg}	1.96±0.69 ^{abc}	12.03±0.21 ^{cd}	38.61±1.09 ^c	5.00±0.04 ^c	5.44±0.02 ^d	14.18±0.86 ^e	319.43
SBDDSB 20 min	96.01±0.05 ^{bcd}	3.98±0.05 ^{def}	14.79±0.72 ^g	43.49±1.22 ^d	3.00±0.01 ^a	6.28±0.00 ^f	15.44±1.05 ^{fg}	368.83
SBDDSB 40 min	95.34±1.11 ^{bc}	4.65±1.11 ^{def}	13.73±1.11 ^{ef}	29.93±0.87 ^a	4.00±0.16 ^b	6.28±0.17 ^f	1.27±0.00 ^a	248.37
BDDSB 20 min	95.73±0.33 ^{bcd}	4.26±0.33 ^{def}	13.79±0.74 ^f	34.30±0.95 ^b	4.00±0.04 ^b	6.33±0.01 ^{fg}	5.92±0.21 ^b	284.99
BDDSB 40 min	95.34±0.37 ^{bc}	4.65±0.37 ^{ef}	13.45±0.73 ^{ef}	40.43±0.17 ^{cd}	4.00±0.00 ^b	5.46±0.05 ^d	12.87±0.07 ^{de}	334.25
ORSB 15 min	94.85±0.38 ^b	5.14±0.38 ^f	8.57±0.02 ^a	36.05±0.60 ^{bc}	4.00±0.00 ^b	6.82±0.03 ^g	11.52±0.64 ^{cd}	267.41
ORSB 30 min	98.27±1.04 ^{efg}	1.72±1.04 ^{abc}	11.70±0.17 ^c	33.80±0.13 ^b	5.00±0.05 ^c	5.14±0.11 ^c	10.24±0.32 ^c	281.46
PRSB 15 min	98.26±1.04 ^{efg}	1.73±1.04 ^{abc}	9.78±0.79 ^b	40.30±2.65 ^{cd}	4.00±0.00 ^b	4.22±0.18 ^a	20.57±1.08 ^h	331.5
PRSB 30 min	98.52±0.04 ^{fg}	1.47±0.04 ^{bc}	11.46±0.57 ^c	39.55±1.11 ^{cd}	4.00±0.00 ^b	5.94±0.00 ^c	16.68±0.90 ^g	328.06

n=2. Values are presented as mean ± standard deviation. ^(a-h) values of the same column with different superscripts are significantly different at $p < 0.05$. **USB (Control 1)**: Untreated Soya bean; **SDSB (Control 2)**: Soaked, De-hulled and Dried Soya bean; **SDBDSB 20 min**: Soaked, De-hulled, Boiled for 20 min and Dried Soya bean; **SDBDSB 40 min**: Soaked, De-hulled, Boiled for 40 min and Dried Soya bean; **SDDPRSB 10 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 10 min; **SDDPRSB 20 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 20 min; **SDDORSB 10 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 10 min; **SDDORSB 20 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 20 min; **SBDDSB 20 min**: Soaked, Boiled for 20 min, De-hulled, and Dried Soya bean; **SBDDSB 40 min**: Soaked, Boiled for 40 min, De-hulled, and Dried Soya bean; **BDDSB 20 min**: Boiled for 20 min, De-hulled and Dried Soya bean; **BDDSB 40 min**: Boiled for 40 min, De-hulled and Dried Soya bean; **ORSB 15 min**: Oven Roasted Soya bean for 15 min; **ORSB 30 min**: Oven Roasted Soya bean for 30 min; **PRSB 15 min**: Pot Roasted Soya bean for 15 min; **PRSB 30 min**: Pot Roasted Soya bean for 30 min.

Results of the ash and fiber contents showed that they ranged between 3.00 - 5.00 and 4.22 - 6.84% respectively. These values were close to 2.0 - 4.2 and 2.3 - 4.5% for the ash and fiber contents respectively obtained by Ukwuru (2003) with soy flour. Similar results were published by Eshun (2012) with three soya bean varieties from Ghana (1.01 - 1.67 and 2.97 - 3.01% for ash and crude fibers respectively). The ash content usually gives an idea on how much minerals are present in a food sample. For the fibers, they inform on the fact that a specific food sample can be useful in maintaining the gastrointestinal tract in good health (Maidala *et al.*, 2013).

The lipid content in this study ranged between 8.75 - 14.79%. These values were significantly ($p < 0.05$) lower compared to 12.27 - 18.03, 21.4 - 27.2, 19.21 - 19.59% reported by (Maidala *et al.*, 2013; Ashworth and Draper, 1992; Agume *et al.*, 2017) respectively. The nature of the extraction solvent, the soya bean variety, the nature of the soil and location as well as the climatic conditions might be responsible for the variations observed (Kim and Choe, 2004; Shan *et al.*, 2005). A significant ($p < 0.05$) increase in lipid content was observed with samples SDBDSB, SDDPRSB, SDDORSB, SBDDSB and BDDSB. This can be explained by the dissociation of bound lipids due to high temperature since it easily breaks down non-covalent bonds (Ragab *et al.*, 2003). Alteration of cell structure during processing can also explain the increase in lipid content observed (Cuevas-Rodriguez *et al.*,

2004). An increase in oil content after processing has been demonstrated for cereal seeds amongst which are soya bean, sesame, maize and millet (Sade, 2009; Oboh *et al.*, 2010; Makinde and Akinoso, 2013; Agume *et al.*, 2017).

Concerning the protein content, results showed that they were ranged between 29.93 - 43.05% which is close to 35.5 - 44.1, 40.13 - 56.66, 37.56 - 38.09% obtained by Agume *et al.* (2017), Maidala *et al.* (2013) and Suryana *et al.* (2022) with soya bean flours respectively. A significant ($p < 0.05$) decrease in protein content with processing time was recorded with sample SBDDSB. This can be due to the fact that they were used as substrates in non-enzymatic browning reactions (Tenyang *et al.*, 2021). Similar observations were made by Agume *et al.* (2017) who demonstrated that the protein content of roasted and unroasted soya bean significantly decreased with processing time. Similar results were also reported by Djikeng *et al.* (2017) during boiling and roasting of walnut seed.

Results also showed that the carbohydrate content for soyabean samples was ranged 1.27 - 20.57% which is significantly ($p < 0.05$) lower compared to 19.7 - 37.9% reported by Ukwuru (2003) with flours from different soya bean varieties. A significant decrease in this parameter was observed with samples SDBDSB, SDDPRSB, SDDORSB and PRSB compared to the controls. This can be attributed to the dissociation of bound carbohydrates due to high temperature (Ragab *et al.*, 2003). The degradation of cell structure during processing can also explain the increase observed (Cuevas-Rodriguez *et al.*, 2004). The significant decrease in carbohydrate content obtained with samples SBDDSB might be due to the Maillard reaction. It has been proven that carbohydrates and protein are the substrates of non-enzymatic browning reactions. Since this reaction is catalyzed by high temperature it might have been facilitated by the processing method applied which resulted in the decrease observed. Similar result was previously recorded with the protein content of the same sample confirming that they might have been used in the condensation reaction which is the initiation step of the Maillard reaction. These results are in agreement with those of Tenyang *et al.* (2021) who showed that the carbohydrate content of brown and white sesame seeds significantly decreased during processing.

The calculation of the energy value in kcal showed that it ranged between 267.41 - 367.14 kcal. This can significantly contribute to the average daily energy of 2000 - 2500 kcal needed by adults to maintain a healthy body weight (CFS, 2009). Results showed that the energy value of soya bean significantly ($p < 0.05$) increased with processing. This can be due to an increase in macronutrients facilitated by the impact of heat. Soya bean can therefore provide an interesting amount of calories in the diet.

3.2.3 Mineral Content

The changes in some mineral content of soya bean during processing are presented in Table 4. Results of the changes in iron content of soya bean during processing showed that it was ranged between 4.46 - 9.82 mg/100 g which was significantly higher than 1.3 - 2.9 mg/100 g reported by Ukwuru (2003) with flours from different soya bean varieties. However it was considerably lower than 16 mg/100 g obtained by Carrera *et al.* (2011). A significant decrease in iron content was registered with ORSB and PRSB. This result is in agreement with the findings of Djikeng *et al.* (2017) who demonstrated that roasting significantly reduce the iron content of walnut. It is well known that iron is an important element of hemoglobin and many enzymes. Its deficiency is associated with anemia which is a severe nutritional disease (Loumouamou *et al.*, 2010).

Table 4. Variations in selected mineral composition of soya bean during processing

Samples	Iron (mg/100g)	Calcium (mg/100g)	Phosphorus (mg/100g)	Magnesium (mg/100g)	Zinc (mg/100g)	Potassium (mg/100g)	Sodium (mg/100g)
USB (Control 1)	8.19±0.10 ^d	172.00±0.01 ^b	129.42±2.32 ^b	43.74±0.79 ^c	1.90±0.15 ^a	180.00±0.00 ^a	15.00±0.31 ^a
SDSB (Control 2)	7.57±0.24 ^{cd}	304.00±1.14 ⁱ	528.43±1.34 ^k	43.74±1.45 ^e	7.61±0.08 ^d	710.60±2.65 ^d	101.00±1.27 ^g
SDBDSB 20 min	7.10±0.41 ^{bcd}	240.00±3.33 ^f	372.21±4.55 ^f	38.88±2.12 ^d	7.61±0.04 ^d	1499.30±10.24 ^e	86.00±2.36 ^b
SDBDSB 40 min	8.02±0.20 ^d	188.00±5.14 ^c	305.9±6.55 ^d	68.04±0.98 ^j	2.74±0.00 ^b	1093.40±3.12 ^m	86.00±3.14 ^b
SDDPRSB 10 min	7.03±0.00 ^{bcd}	184.00±0.87 ^c	467.74±4.02 ^h	58.32±1.16 ^h	7.30±0.31 ^d	871.10±2.41 ^e	61.00±2.55 ^d
SDDPRSB 20 min	9.82±1.12 ^e	336.00±4.47 ^j	668.92±3.25 ⁿ	38.88±0.72 ^d	6.84±0.00 ^d	1392.00±9.50 ^l	150.00±1.49 ^h
SDDORSB 10 min	6.97±0.00 ^{bcd}	336.00±2.01 ^j	545.29±4.67 ^l	48.60±2.23 ^f	4.31±0.13 ^c	322.10±3.62 ^b	101.00±2.14 ^g
SDDORSB 20 min	6.79±0.18 ^{bcd}	256.00±4.55 ^g	507.08±6.08 ⁱ	97.20±0.56 ^l	5.85±0.10 ^e	913.60±2.41 ^f	101.00±0.77 ^g
SBDDSB 20 min	7.32±0.26 ^{cd}	256.00±2.41 ^g	445.26±0.86 ^g	53.46±0.00 ^g	4.27±0.95 ^c	1445.20±0.74 ⁱ	86.00±0.11 ^b
SBDDSB 40 min	6.38±0.00 ^{bc}	200.00±1.74 ^d	525.06±2.08 ^k	87.48±2.44 ^k	7.09±0.52 ^d	1499.30±6.66 ^h	61.00±2.74 ^d
BDDSB 20 min	7.78±0.03 ^d	288.00±4.22 ^h	554.28±4.15 ^m	34.02±1.57 ^c	5.32±0.66 ^e	1784.40±14.78 ^j	73.00±0.00 ^c
BDDSB 40 min	7.38±0.68 ^{cd}	216.00±0.00 ^e	513.82±0.12 ^j	29.16±0.00 ^b	4.23±0.00 ^c	1238.30±2.76 ^k	73.00±3.55 ^c
ORSB 15 min	6.33±0.55 ^{bc}	184.00±3.58 ^c	327.25±0.00 ^e	48.60±0.21 ^f	5.85±0.14 ^e	600.40±4.25 ^c	50.00±1.24 ^f
ORSB 30 min	6.18±0.10 ^b	216.00±4.10 ^e	516.07±4.25 ^j	63.18±2.41 ⁱ	4.43±0.00 ^c	1001.50±2.75 ^g	101.00±0.26 ^g
PRSB 15 min	5.86±0.00 ^b	160.00±1.50 ^a	108.09±0.00 ^a	24.30±1.25 ^a	3.14±0.08 ^b	871.10±0.00 ^f	30.00±1.20 ^f
PRSB 30 min	4.46±0.01 ^a	256.00±7.41 ^g	191.26±0.55 ^c	34.02±0.00 ^c	5.54±0.02 ^e	1499.30±2.60 ^h	73.00±0.00 ^c

n=2. Values are presented as mean \pm standard deviation. ^(a-n) values of the same column with different superscripts are significantly different at $p < 0.05$. **USB (Control 1)**: Untreated Soya bean; **SDSB (Control 2)**: Soaked, De-hulled and Dried Soya bean; **SDBDSB 20 min**: Soaked, De-hulled, Boiled for 20 min and Dried Soya bean; **SDBDSB 40 min**: Soaked, De-hulled, Boiled for 40 min and Dried Soya bean; **SDDPRSB 10 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 10 min; **SDDPRSB 20 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 20 min; **SDDORSB 10 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 10 min; **SDDORSB 20 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 20 min; **SBDDSB 20 min**: Soaked, Boiled for 20 min, De-hulled, and Dried Soya bean; **SBDDSB 40 min**: Soaked, Boiled for 40 min, De-hulled, and Dried Soya bean; **BDDSB 20 min**: Boiled for 20 min, De-hulled and Dried Soya bean; **BDDSB 40 min**: Boiled for 40 min, De-hulled and Dried Soya bean; **ORSB 15 min**: Oven Roasted Soya bean for 15 min; **ORSB 30 min**: Oven Roasted Soya bean for 30 min; **PRSB 15 min**: Pot Roasted Soya bean for 15 min; **PRSB 30 min**: Pot Roasted Soya bean for 30 min.

Concerning the calcium and phosphorus contents, results showed that they were ranged between 160.00 - 336.00 and 108.09 - 668.92 mg/100 g respectively. The amount of calcium obtained in this study was close to 238.00-282.33 mg/100g obtained by Saxena and Vyas (2016) with soya bean varieties. For the phosphorus content, its concentration was slightly higher than 318.5 - 430.9 mg/100g reported by Niyibituronsa *et al.* (2019) with six soya bean varieties (LOCAL, SB24, PEKA6, SC.SEQUEL, SC.SAGA, SC.SQUIRE) grown in Rwanda. A significant ($p < 0.05$) increase in phosphorus and calcium contents was registered in all processed samples compared to the raw controls. This can be attributed to the reduction in anti-nutritional factors which has released complexed minerals under the effect of heat (Makinde and Akinosi, 2013). The important reduction in concentration of these minerals in boiled samples compared to control 2 (SDSB) can be the consequence of their leaching. These two minerals are well known for their role in bone mineralization (James, 2000). These results are in line with those of Djikeng *et al.* (2017) who showed that boiling and roasting considerably decrease the phosphorus and calcium content of walnut compared to their dry control.

The outcomes of the analysis of the magnesium content of soya bean exhibited values ranged between 24.30 - 97.20 mg/100 g respectively which were lower than 141.9 - 167.2 mg/100 g and 81.3 - 98.0 mg/100 g obtained by Niyibituronsa *et al.* (2019) and Ukwuru (2003) with different soya bean varieties. Results showed significant ($p < 0.05$) decrease in this parameter with BDDSB and PRSB while it considerably increased with the other processing methods. The decrease in magnesium content in BDDSB can be due to the boiling process which has leached out part of this mineral. The increase recorded with other processing methods can be due to the destruction of anti-nutritional factors which release the complex magnesium responsible of its rise in concentration (Makinde and Akinosi, 2013). Similar findings were obtained by Djikeng *et al.* (2017, 2022) with walnut and tigernut respectively.

The data of the zinc content revealed that this parameter was significantly ($p < 0.05$) higher in processed samples compared to control 1 (USB). The destruction of anti-nutritional factors by the heat might be responsible of this augmentation which marks the release of the bound zinc (Obboh *et al.*, 2010). A significant ($p < 0.05$) decrease in zinc content during processing was recorded compared to control 2 (SDSB). This might be attributed to its leaching in boiling water for some samples. The amount zinc obtained in this study ranged between 1.90 - 7.61 mg/100 g which was slightly higher than 4.8 mg/100 g reported by Carrera *et al.* (2011).

The results of potassium and sodium contents showed that they are ranged 180.00 - 1784.40 and 15.00 - 150.00 mg/100 g respectively which are generally higher than 33.00 - 47.50 and 20.10 - 27.40 mg/100 g obtained for these same parameters by Ukwuru (2003) with flour from three different soya bean varieties. However the amount of potassium found in this work was lower than 1451.2 - 1857.5 mg/100 g revealed by Niyibituronsa *et al.* (2019) with soya bean varieties from Rwanda. The crop variety and many other factors as previously mentioned can explain the variations observed. There was a significant ($p < 0.05$) increase in these minerals in processed samples compared to control 1 (USB). This can be explained by the disruption of the membrane of cell plants during processing which releases more of these elements. However, compared to control 2 (SDSB) it can be noted that soaking, de-hulling, boiling and drying (SDBDSB 20 and 40 min), soaking, boiling, de-hulling and drying (SBDDSB 20 and 40 min), boiling, de-hulling and drying (BDDSB 20 and 40 min) and pot roasting (PRSB 15 and 30 min) significantly ($p < 0.05$) reduce the sodium content of soya bean. The decrease recorded in boiled samples can be due to their leaching into the boiling water (Yokota *et al.*, 2007). Similar results were previously reported by Djikeng *et al.* (2017, 2022) with walnut and tigernut respectively. The presence of these mineral in soya bean is of great importance due to their role in hypertension. They have been demonstrated to help to control high blood pressure (James, 2000).

3.2.4 Changes in Some Anti-nutritional Components of Soya Bean

The influence of different processing methods on the phytate, oxalate and tannin contents of soya bean is presented in Table 5. Results revealed that these parameters were ranged between 267.77 - 291.61, 1.00 - 126.39 and 146.25 - 262.50 mg/100 g respectively. These values were significantly higher than 29.70 - 45.10, 15.00 - 25.00 and 4.57 - 8.07 mg/100 g reported by Maida *et al.* (2013) during processing of soya bean. However they were lower than 3.94 - 14.80 and 6.30 - 15.90 mg/g obtained by Sharma *et al.* (2013) for phytates and tannins respectively in soya bean. Results showed that BDDSB, PRSB and ORSB significantly ($p < 0.05$) reduced the phytate content of soya bean. Similarly, the oxalate content was considerably ($p < 0.05$) reduced by all processing techniques. These changes can be attributed to the thermal decomposition of the anti-nutritional factors or their leaching in soaking or boiling water. These results are in line with the finding of Adekanmi *et al.* (2009) who reported that the anti-nutritional factors present in food samples significantly decrease during soaking and roasting. Boiling was also demonstrated as being efficient in minimizing the anti-nutrients of crops (Cvelier and Maillard, 2012). The presence of phytates and oxalate in food samples has great influence on the availability of some minerals as well as the functional properties of carbohydrates and proteins (Wcislo, 2014).

Table 5. Changes in anti-nutrient contents of soya bean flour during processing

Samples	Phytate (mg/100 g)	Oxalate(mg/100 g)	Tannin (mg/100 g)
USB (Control 1)	290.10±3.03 ^c	126.31±1.35 ^h	191.25±0.01 ^d
SDSB (Control 2)	287.17±3.61 ^c	122.80±3.24 ^g	208.75±0.21 ^f
SDBDSB 20 min	292.92±2.81 ^c	67.76±3.68 ^d	171.25±0.02 ^c
SDBDSB 40 min	282.72±2.89 ^{bc}	34.28±8.83 ^c	192.50±1.02 ^d
SDDPRSB 10 min	280.10±2.24 ^b	117.55±2.40 ^{fg}	206.25±0.23 ^e
SDDPRSB 20 min	281.81±2.69 ^{bc}	115.77±5.25 ^{fg}	291.25±0.82 ^j
SDDORSB 10 min	287.67±2.61 ^c	117.87±0.87 ^{fg}	170.00±0.67 ^c
SDDORSB 20 min	290.98±0.92 ^c	117.15±1.81 ^{fg}	256.25±1.20 ^h
SBDDSB 20 min	291.61±3.40 ^c	22.63±4.02 ^b	123.75±0.55 ^a
SBDDSB 40 min	290.65±2.71 ^c	1.00±0.00 ^a	231.25±0.77 ^g
BDDSB 20 min	278.48±4.00 ^b	90.92±3.84 ^e	262.50±0.34 ⁱ
BDDSB 40 min	267.77±0.46 ^a	21.21±1.86 ^b	146.25±0.22 ^b
ORSB 15 min	282.12±2.98 ^{bc}	122.01±2.08 ^g	171.25±1.02 ^c
ORSB 30 min	279.19±0.46 ^b	112.40±0.55 ^f	333.75±2.45 ^k
PRSB 15 min	271.91±2.28 ^a	119.18±2.44 ^{fg}	207.50±0.28 ^{ef}
PRSB 30 min	278.18±1.68 ^b	114.53±0.87 ^{fg}	505.00±2.55 ^l

n=3. Values are presented as mean ± standard deviation. ^(a-l) values of the same column with different superscripts are significantly different at $p < 0.05$. **USB (Control 1)**: Untreated Soya bean; **SDSB (Control 2)**: Soaked, De-hulled and Dried Soya bean; **SDBDSB 20 min**: Soaked, De-hulled, Boiled for 20 min and Dried Soya bean; **SDBDSB 40 min**: Soaked, De-hulled, Boiled for 40 min and Dried Soya bean; **SDDPRSB 10 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 10 min; **SDDPRSB 20 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 20 min; **SDDORSB 10 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 10 min; **SDDORSB 20 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 20 min; **SBDDSB 20 min**: Soaked, Boiled for 20 min, De-hulled, and Dried Soya bean; **SBDDSB 40 min**: Soaked, Boiled for 40 min, De-hulled, and Dried Soya bean; **BDDSB 20 min**: Boiled for 20 min, De-hulled and Dried Soya bean; **BDDSB 40 min**: Boiled for 40 min, De-hulled and Dried Soya bean; **ORSB 15 min**: Oven Roasted Soya bean for 15 min; **ORSB 30 min**: Oven Roasted Soya bean for 30 min; **PRSB 15 min**: Pot Roasted Soya bean for 15 min; **PRSB 30 min**: Pot Roasted Soya bean for 30 min.

The majority of treatment considerably ($p < 0.05$) augmented the tannin content of soya bean while this parameter reduced with BDDSB. The increase in tannin content with processing can be explained by the fact that during heat processing they were released from the protein to which they were bound. Tannins are polyphenols with good antioxidant activity. Their trend was close to that of the total phenolic content obtained in this study. Boiling, de-hulling and drying (BDDSB) might easily decompose this molecule reason why their concentration decreases. The anti-nutritional action of tannins is the inhibition of protein digestibility and reduction of the absorption of important compounds present in food samples (Hendek and Bektas, 2018).

3.2.5 Impact of Processing on the Functional Properties of Defatted and Non-defatted Soya Bean Flours

3.2.5.1 Water and Oil Holding Capacity

The water and oil holding capacities are presented on figures 1 (A and B).

The water holding capacity (WHC) measures trapped water which is made up of bound and free water. It is the ability of a substance to incorporate water molecules (Mohajan *et al.*, 2018). Results (Figure 1A) showed that the WHC significantly ($p < 0.05$) decreased with roasting time. Generally the WHC of the defatted samples was higher than that of non-defatted ones. The WHC of the analyzed flours was ranged between 15-33% which is lower than 257.74 - 322.15 and 197.00 - 203.33% reported by Eshun (2012) and Dobhal and Raghuvanshi (2018)

with flours from different soya bean varieties and black soya bean respectively. The difference in varieties can explain the variations observed. The decrease in WHC registered with treatments involving roasting can be attributed to heat treatments that have degraded the tertiary structure of the proteins present (Osundahunsi *et al.*, 2003). This result is not in agreement with the statement of Giami (1993) who reported that high temperature processing increases the water holding capacity of beans and cow peas. The high WHC registered in defatted samples compared to non-defatted ones can be related to the elimination of fats from the flour which exposes the polar groups in proteins to their environment, therefore facilitating the water absorption (Lin *et al.*, 1974). The WHC is an indicator of the amount of water that can be used for gelatinization process and low WHC is useful for making thinner gruels (Singh, 2012; Alloysius *et al.*, 2018).

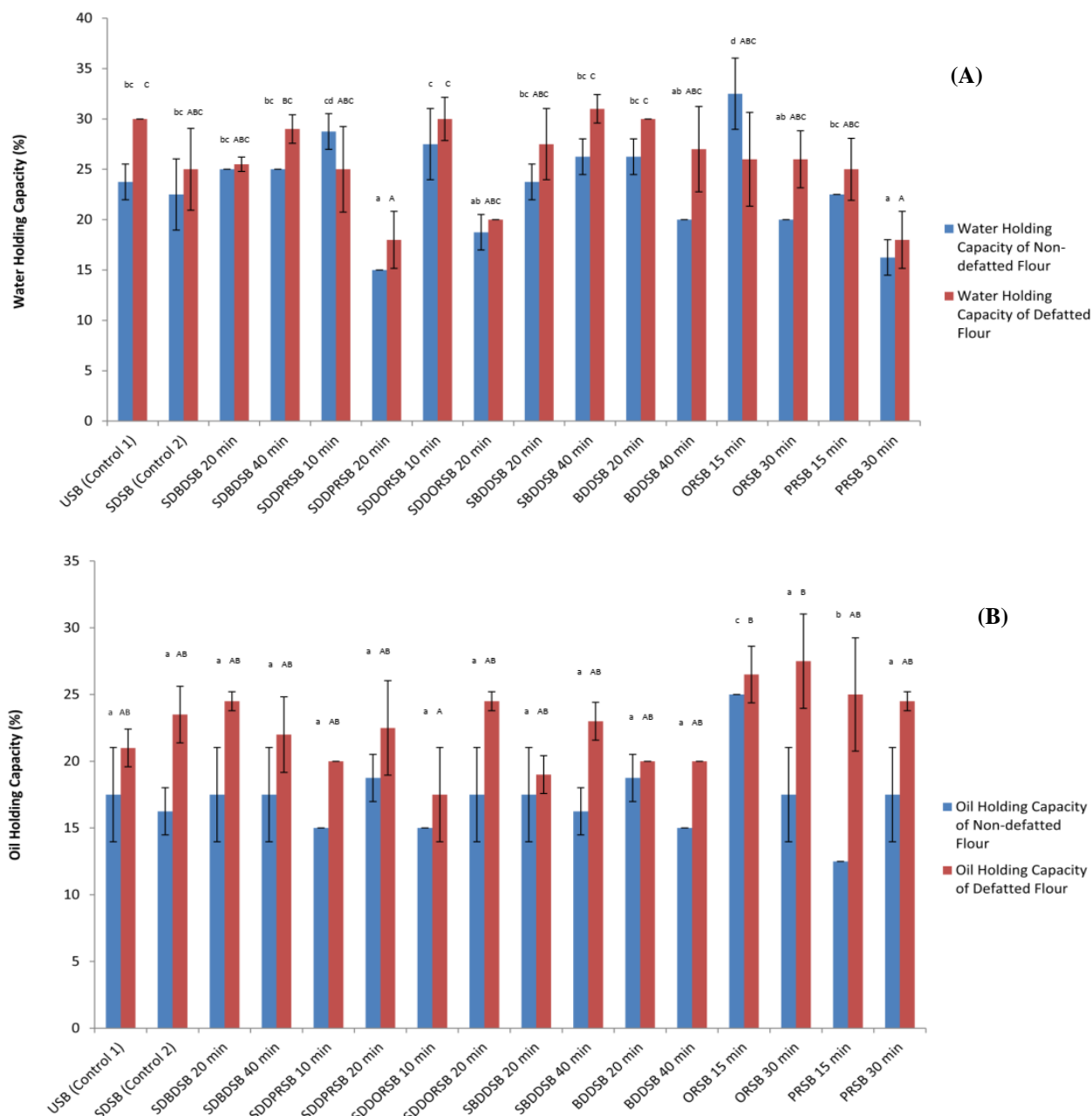


Figure 1. Changes in water (A) and oil (B) holding capacities of non-defatted and defatted soya bean flour during processing

n=2. Values are presented as mean ± standard deviation. ^(a-d) values of water holding capacity of non-defatted flour with different superscripts are significantly different at p<0.05. ^(A-C) values of water holding capacity of defatted flour with different superscripts are significantly different at p<0.05. **USB (Control 1)**: Untreated Soya bean; **SDSB (Control 2)**: Soaked, De-hulled and Dried Soya bean; **SDBDSB 20 min**: Soaked, De-hulled, Boiled

for 20 min and Dried Soya bean; **SDBDSB 40 min**: Soaked, De-hulled, Boiled for 40 min and Dried Soya bean; **SDDPRSB 10 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 10 min; **SDDPRSB 20 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 20 min; **SDDORSB 10 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 10 min; **SDDORSB 20 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 20 min; **SBDDSB 20 min**: Soaked, Boiled for 20 min, De-hulled, and Dried Soya bean; **SBDDSB 40 min**: Soaked, Boiled for 40 min, De-hulled, and Dried Soya bean; **BDDSB 20 min**: Boiled for 20 min, De-hulled and Dried Soya bean; **BDDSB 40 min**: Boiled for 40 min, De-hulled and Dried Soya bean; **ORSB 15 min**: Oven Roasted Soya bean for 15 min; **ORSB 30 min**: Oven Roasted Soya bean for 30 min; **PRSB 15 min**: Pot Roasted Soya bean for 15 min; **PRSB 30 min**: Pot Roasted Soya bean for 30 min

For the oil absorption capacity (OHC) (Figure 1B), generally, no significant difference was recorded in this parameter with defatted and non-defatted soya bean flours. The OHC was ranged between 12 - 25% for non-defatted samples and 17.5 - 20% for defatted ones. These values were significantly lower than 107 - 216% obtained with non-defatted and defatted maize flours (Shad *et al.*, 2013). Dobhal and Raghuvanshi (2018) reported oil absorption capacities of 93.33 - 126.67% with raw and germinated black soya bean flours respectively. The crop composition as well as the difference in variety can justify the changes observed. OHC of food is attributed to the physical adsorption of oil which is technologically important in flavor retention (Yadahally *et al.*, 2008). The fact that the OHC of defatted flours was in general higher than that of non-defatted ones, can be attributed as previously mentioned with the WHC to the removal of fat which causes the exposure of hydrophilic functions in proteins (Lin *et al.*, 1974). Oil-flour interaction is important in food formulation due to its influence on the nutritional, technological and sensory properties of food stuffs.

3.2.5.2 Swelling Capacity

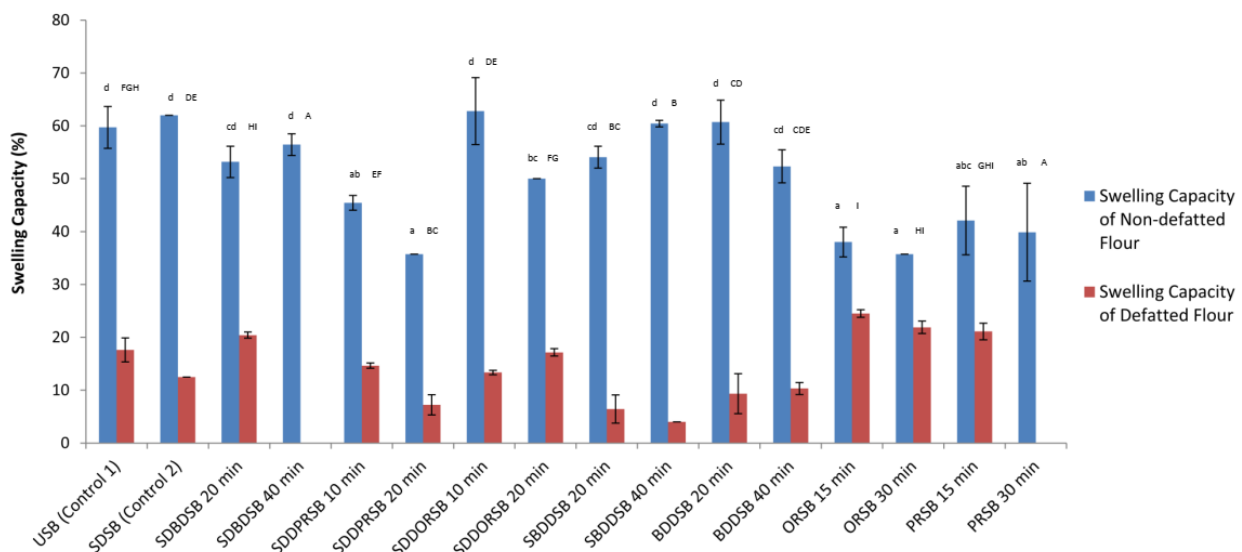


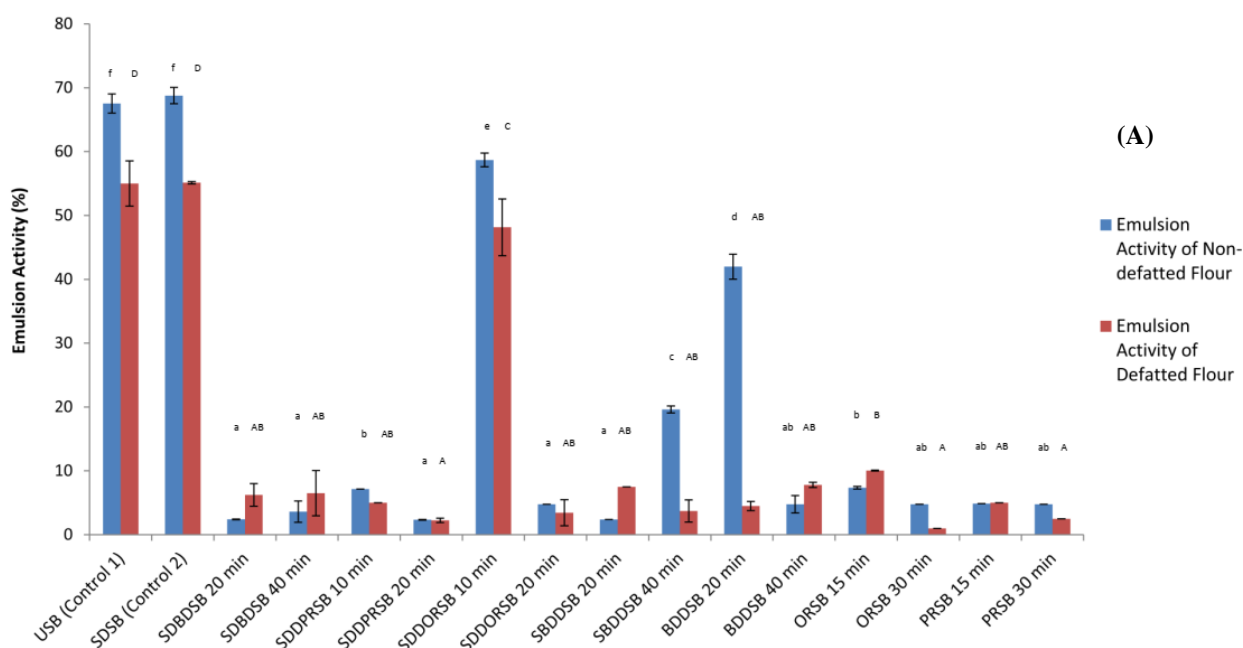
Figure 2. Variations in swelling capacity of non-defatted and defatted soya bean flour during processing

n=2. Values are presented as mean \pm standard deviation. ^(a-d) values of water holding capacity of non-defatted flour with different superscripts are significantly different at $p < 0.05$. ^(A-C) values of water holding capacity of defatted flour with different superscripts are significantly different at $p < 0.05$. **USB (Control 1)**: Untreated Soya bean; **SDSB (Control 2)**: Soaked, De-hulled and Dried Soya bean; **SDBDSB 20 min**: Soaked, De-hulled, Boiled for 20 min and Dried Soya bean; **SDBDSB 40 min**: Soaked, De-hulled, Boiled for 40 min and Dried Soya bean; **SDDPRSB 10 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 10 min; **SDDPRSB 20 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 20 min; **SDDORSB 10 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 10 min; **SDDORSB 20 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 20 min; **SBDDSB 20 min**: Soaked, Boiled for 20 min, De-hulled, and Dried Soya bean; **SBDDSB 40 min**: Soaked, Boiled for 40 min, De-hulled, and Dried Soya bean; **BDDSB 20 min**: Boiled for 20 min, De-hulled and Dried Soya bean; **BDDSB 40 min**: Boiled for 40 min, De-hulled and Dried Soya bean; **ORSB 15 min**: Oven Roasted Soya bean for 15 min; **ORSB 30 min**: Oven Roasted Soya bean for 30 min; **PRSB 15 min**: Pot Roasted Soya bean for 15 min; **PRSB 30 min**: Pot Roasted Soya bean for 30 min

The determination of the swelling capacity informs on the ability of starch to absorb water and swell. It is a very crucial parameter used to modify the volume of food samples in order to make them acceptable by consumers (Ayodele and Beatrice, 2015). The swelling capacity of defatted and non-defatted soya bean flour samples is presented in figure 2. The SC of non-defatted samples was significantly ($p < 0.05$) higher than that of defatted samples. Generally, treatments involving roasting were found to have a significant effect on the SC of both defatted and non-defatted soya bean flours. The SC of defatted flours was ranged between 4 - 40% while that of non-defatted samples fell within 35 - 65%. A swelling capacity of 29% was reported by Dobhal and Raghuvanshi (2018). The decrease in swelling capacity registered with treatments involving roasting can be attributed to the thermal decomposition of starch due to high temperatures or in some cases, by enzymatic reactions during soaking. Similar results were obtained by Julianti *et al.* (2017) with the increase of soy flour substitution in formulated flours. The fact that the swelling capacities of non-defatted samples were significantly higher than that of defatted samples is contradictory to the statement of Shimelis *et al.* (2006) who mentioned that the decrease in swelling capacity can be the result of the inhibitory action of lipids on the ability of starch to swell. The starch-protein interaction can explain the lowered swelling capacity of the defatted flours.

3.2.5.3 Emulsion Activity and Stability

The variations in emulsion activity (EA) and stability (ES) of defatted and non-defatted soya bean flours sample are presented in Figures 3 (A and B). These parameters are related to the quantity of oil emulsified and stabilized by proteins in a specific amount of flour (Shad *et al.*, 2013). The difference between these two parameters is linked to soluble and insoluble proteins, and other substances such as lipids, sterols, starch etc of the flour. The ability of proteins to increase the formation and stability of emulsion is capital for food application especially in coffee, cake etc (Elkhalifa and Bernhardt, 2010). It can be observed that all treatments significantly decreased ($p < 0.05$) the EA and ES of defatted and non-defatted flours. This decrease can be attributed to the destruction of proteins and other substances such as starch during treatments. This might have affected the solubility and hydrophobicity of proteins (Lalude and Fashakin, 2006; Kaushal *et al.*, 2012). These results are in accordance with the findings of Igbabul *et al.* (2012) and Dobhal and Raghuvanshi (2016) who respectively showed that the emulsion capacity of brown hamburger beans, sweet detar seed flours and black soya bean were decreasing during fermentation and germination.



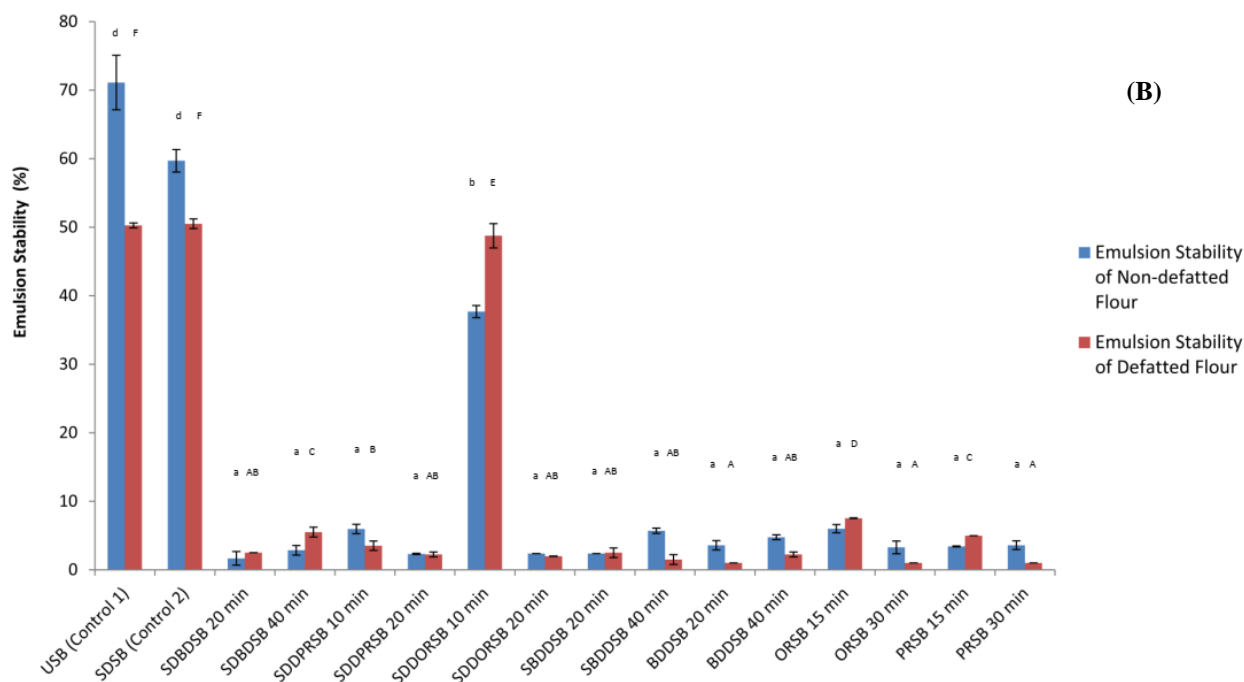


Figure 3. Changes in emulsion activity (A) and stability (B) of non-defatted and defatted soya bean flours during processing

n=2. Values are presented as mean \pm standard deviation. ^(a-f) values of water holding capacity of non-defatted flour with different superscripts are significantly different at $p < 0.05$. ^(A-F) values of water holding capacity of defatted flour with different superscripts are significantly different at $p < 0.05$. **USB (Control 1)**: Untreated Soya bean; **SDSB (Control 2)**: Soaked, De-hulled and Dried Soya bean; **SDBDSB 20 min**: Soaked, De-hulled, Boiled for 20 min and Dried Soya bean; **SDBDSB 40 min**: Soaked, De-hulled, Boiled for 40 min and Dried Soya bean; **SDDPRSB 10 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 10 min; **SDDPRSB 20 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 20 min; **SDDORSB 10 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 10 min; **SDDORSB 20 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 20 min; **SBDDSB 20 min**: Soaked, Boiled for 20 min, De-hulled, and Dried Soya bean; **SBDDSB 40 min**: Soaked, Boiled for 40 min, De-hulled, and Dried Soya bean; **BDDSB 20 min**: Boiled for 20 min, De-hulled and Dried Soya bean; **BDDSB 40 min**: Boiled for 40 min, De-hulled and Dried Soya bean; **ORSB 15 min**: Oven Roasted Soya bean for 15 min; **ORSB 30 min**: Oven Roasted Soya bean for 30 min; **PRSB 15 min**: Pot Roasted Soya bean for 15 min; **PRSB 30 min**: Pot Roasted Soya bean for 30 min

3.2.5.4 Loose and Packed Bulk Densities

Bulk density is capital for packaging and dietary bulk requirements. Loose bulk density (LBD) promotes food digestibility and enhances nutrient and energy density that offers additional advantage in food formulation (Oppong *et al.*, 2015; Osundahunsi *et al.*, 2003). The loose and packed bulk densities of soya bean flour samples are presented in figures 4 (A and B). Values of loose and packed bulk densities (PBD) of defatted and non-defatted soya bean flour samples were found to be ranged between 0.3 - 0.5 and 0.5 - 0.7 respectively. These values were close 0.53 - 0.98 and 0.74 - 0.82 obtained by Mohajan *et al.* (2018) and Ukwuru (2003) respectively with different soya bean flour samples. Concerning the loose bulk density (LBD) (Figure 4A), no significant change was recorded in this parameter for defatted and non-defatted samples. However, their values increased more with treatments involving roasting. This signifies that the samples treated with these methods have good physical characteristics for packaging, smooth transportation and storage (Agunbiade and Sanni, 2003). For the packed bulk density (PBD) (Figure 4B), No significant ($p > 0.05$) change in this parameter was registered between defatted and non-defatted samples. The non-significant change in PBD obtained suggest that, the flours obtained upon treatment can serve to improve the thickness of food which is an important parameter taken into consideration during food formulation for babies (Eltayeb *et al.*, 2011).

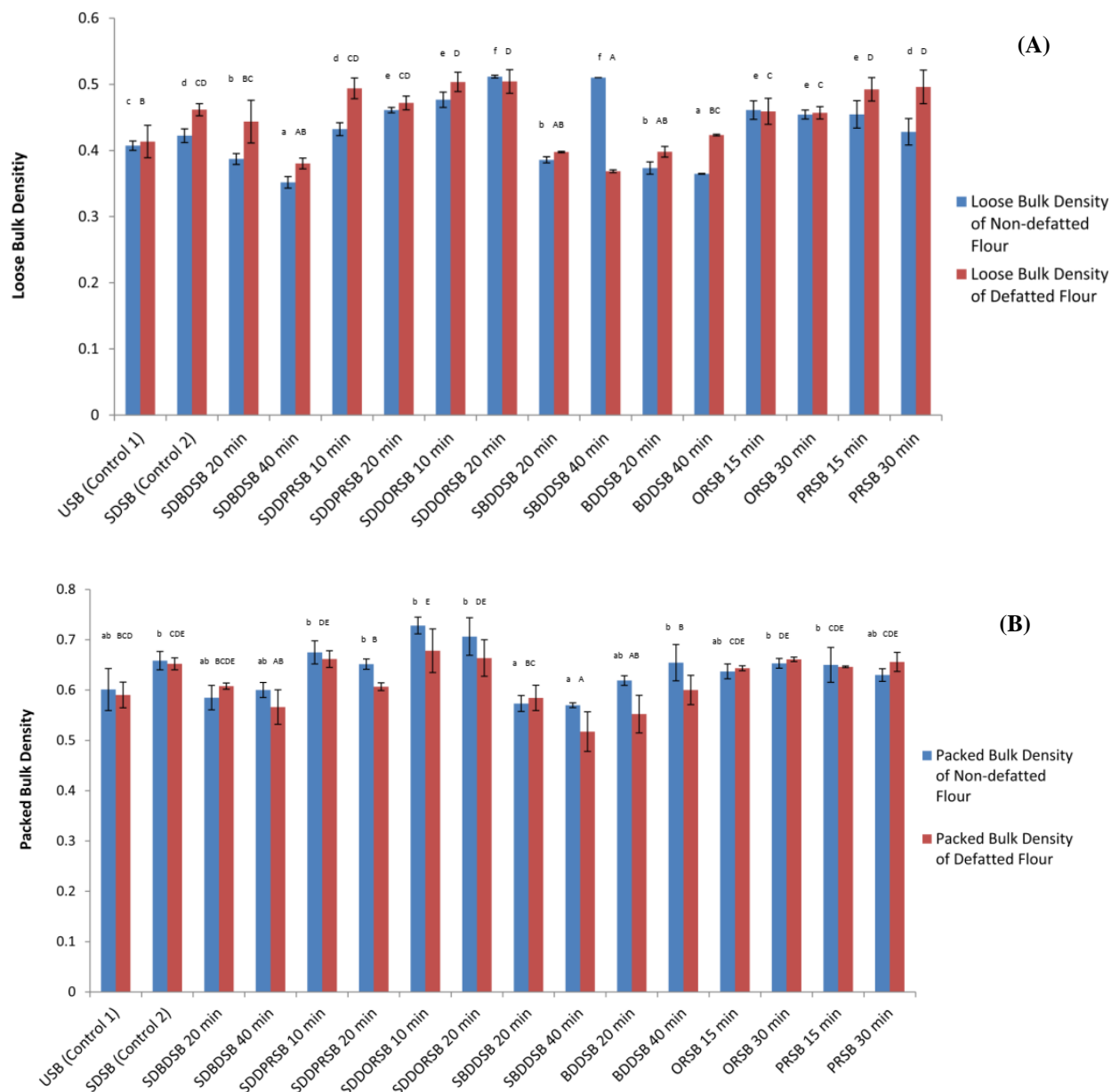


Figure 4. Changes in loose and packed bulk densities of non-defatted and defatted soya bean flour during processing

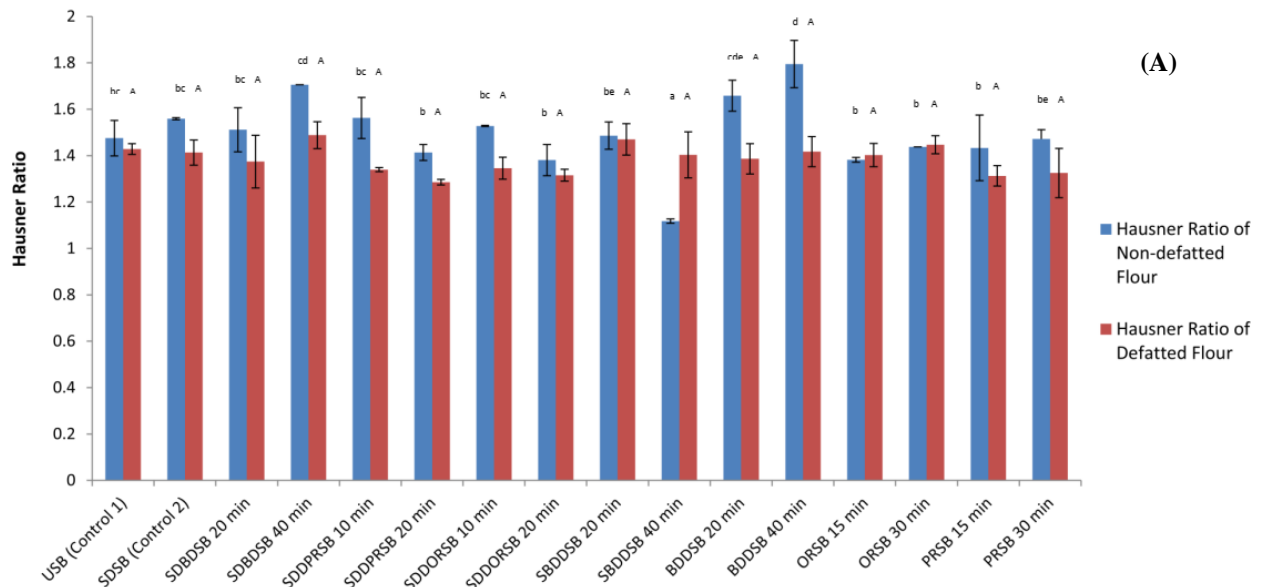
n=2. Values are presented as mean ± standard deviation. ^(a-f) values of water holding capacity of non-defatted flour with different superscripts are significantly different at p<0.05. ^(A-E) values of water holding capacity of defatted flour with different superscripts are significantly different at p<0.05. **USB (Control 1)**: Untreated Soya bean; **SDSB (Control 2)**: Soaked, De-hulled and Dried Soya bean; **SDBDSB 20 min**: Soaked, De-hulled, Boiled for 20 min and Dried Soya bean; **SDBDSB 40 min**: Soaked, De-hulled, Boiled for 40 min and Dried Soya bean; **SDDPRSB 10 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 10 min; **SDDPRSB 20 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 20 min; **SDDORSB 10 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 10 min; **SDDORSB 20 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 20 min; **SBDDSB 20 min**: Soaked, Boiled for 20 min, De-hulled, and Dried Soya bean; **SBDDSB 40 min**: Soaked, Boiled for 40 min, De-hulled, and Dried Soya bean; **BDDSB 20 min**: Boiled for 20 min, De-hulled and Dried Soya bean; **BDDSB 40 min**: Boiled for 40 min, De-hulled and Dried Soya bean; **ORSB 15**

min: Oven Roasted Soya bean for 15 min; **ORSB 30 min:** Oven Roasted Soya bean for 30 min; **PRSB 15 min:** Pot Roasted Soya bean for 15 min; **PRSB 30 min:** Pot Roasted Soya bean for 30 min

3.2.5.5 Hausner Ratio and Porosity

The fluctuations in hausner ratio (HR) and porosity (POR) of defatted and non-defatted soya bean flour samples are presented in Figures 5 (A and B). The changes in hausner ratio (HR) and porosity (POR) during processing showed that, they were ranged between 1.1 - 1.9 and 10 - 43% respectively. The HR value range obtained in this study was close to 1.13 - 1.26, 1.29 - 1.36 and 1.13 - 1.24 reported by Olawoye and Gbadamosi (2017), Adebayo *et al.* (2021) and Bala *et al.* (2020) with *Amarantus viridis* seeds, *Musa* starch and Grass pea flours respectively. Generally, no significant change was recorded between the HR of defatted and non-defatted samples. However, the HR of non-defatted samples was higher than that of defatted ones. It is important to note that the HR values obtained in this study were in general greater than 1 - 1.25 which is the characteristic of flour with excellent and near free flowing property. This suggest that the flour used in this study had a fairly to free flowing behavior (Eltayeb *et al.*, 2011). Similar results were obtained by Djikeng *et al.* (2022) with snail meat power.

Concerning the porosity, the values obtained were similar to 26.90 - 45.53% reported by Olawoye and Gbadamosi (2017) with *Amarantus viridis* seeds flour but higher than 22.73 - 25.74% obtained Adebayo *et al.* (2021) with *Musa* starch flour. The differences observed can be attributed to the difference in plant species. A significant ($p < 0.05$) increase in the POR of non-defatted flour was recorded with the sample boiled for 20 or 40 min, de-hulled and dried (BDDSB 20 and 40 min) and the sample soaked, de-hulled, boiled for 40 min and dried (SDBDSB 40 min). Non-defatted samples exhibited higher POR. This might be an indicator that these treatments promote better transportation, storage and packaging of soya bean flour (Drakos *et al.*, 2017). POR measures the voids between particles of a specific product. The pores formed can easily be filled with water and gases but, they should be continuous on the food product for smooth usage in food technology (Kumar and Saini, 2017).



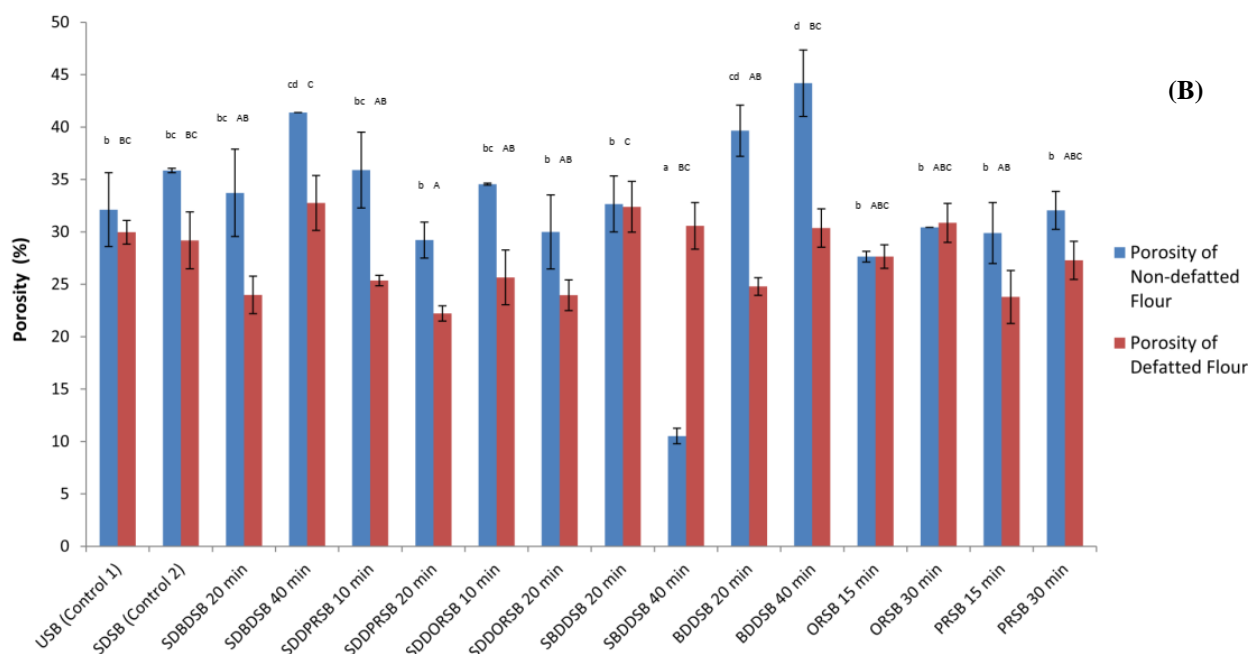


Figure 5. Variations in Hausner ratio (A) and porosity (B) of non-defatted and defatted soya bean flour during processing

$n=2$. Values are presented as mean \pm standard deviation. ^(a-e) values of water holding capacity of non-defatted flour with different superscripts are significantly different at $p<0.05$. ^(A-C) values of water holding capacity of defatted flour with different superscripts are significantly different at $p<0.05$. **USB (Control 1)**: Untreated Soya bean; **SDSB (Control 2)**: Soaked, De-hulled and Dried Soya bean; **SDBDSB 20 min**: Soaked, De-hulled, Boiled for 20 min and Dried Soya bean; **SDBDSB 40 min**: Soaked, De-hulled, Boiled for 40 min and Dried Soya bean; **SDDPRSB 10 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 10 min; **SDDPRSB 20 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 20 min; **SDDORSB 10 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 10 min; **SDDORSB 20 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 20 min; **SBDDSB 20 min**: Soaked, Boiled for 20 min, De-hulled, and Dried Soya bean; **SBDDSB 40 min**: Soaked, Boiled for 40 min, De-hulled, and Dried Soya bean; **BDDSB 20 min**: Boiled for 20 min, De-hulled and Dried Soya bean; **BDDSB 40 min**: Boiled for 40 min, De-hulled and Dried Soya bean; **ORSB 15 min**: Oven Roasted Soya bean for 15 min; **ORSB 30 min**: Oven Roasted Soya bean for 30 min; **PRSB 15 min**: Pot Roasted Soya bean for 15 min; **PRSB 30 min**: Pot Roasted Soya bean for 30 min

3.2.5.6 pH

The change in pH of defatted and non-defatted soya bean flour samples during processing is exhibited in Figure 6. The values for this parameter were ranged between 6 and 7.5. These values were higher than 5.72 - 6.01 obtained by Ajibola *et al.* (2017) with cassava flour, and 5.62 - 5.92 reported by Akoja and Coker (2018) with wheat flour biscuits incorporated with okra powder. However, they were similar to 6.13 - 6.17 gotten from the soup powders with different levels of soya bean flours by Mohajan *et al.* (2018). The nature of the crop and the ingredient used in the formulations can justify the differences observed. Generally, defatted samples exhibited the highest pH values. A significant ($p<0.05$) decrease in pH value of non-defatted flours compared to control 1 (USB) was recorded with control 2 (SDSB), the samples soaked, de-hulled, boiled and dried (SDBDSB 20 and 40 min); soaked, de-hulled, dried and pot roasted (SDDPRSB 10 and 20 min); and soaked, de-hulled, dried and oven roasted (SDDORSB 10 and 20 min). For the defatted flours, the sample oven roasted for 30 min (ORSB 30 min) presented the lowest pH values compared to all the other samples. The decrease in pH registered in non-defatted samples can be due to the production of acids during processing. Since the treatments applied used high temperatures, these might promote the breakdown of triglycerides and the release of free fatty acids which decreased the pH. Other acids such as acetic acid, lactic acid etc, might have been produced during soaking and might have contributed the drop in pH values. Acidic pH was demonstrated to be associated in the development of pleasant taste in food samples (Ogunjobi and Ogunwolu, 2010). These results are in agreement with those of Mohajan *et al.* (2018) who recorded similar drop in pH with soup powders with different levels of soya bean

flours.

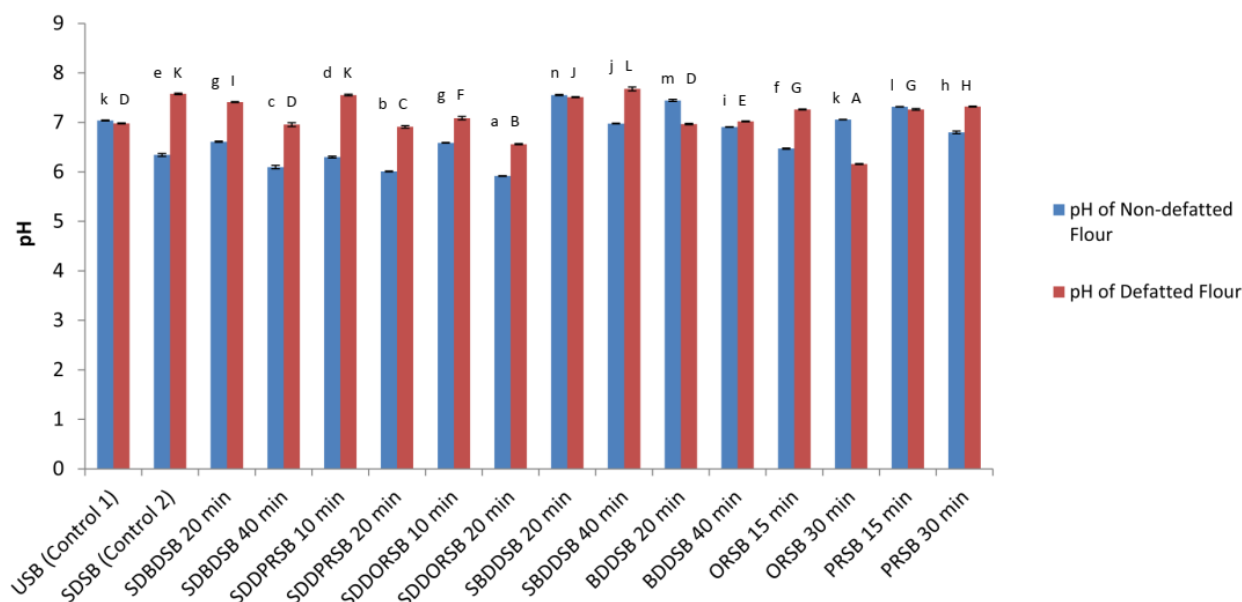


Figure 6. Changes in pH of non-defatted and defatted soya bean flour during processing

$n=2$. Values are presented as mean \pm standard deviation. ^(a-m) values of water holding capacity of non-defatted flour with different superscripts are significantly different at $p<0.05$. ^(A-L) values of water holding capacity of defatted flour with different superscripts are significantly different at $p<0.05$. **USB (Control 1)**: Untreated Soya bean; **SDSB (Control 2)**: Soaked, De-hulled and Dried Soya bean; **SDBDSB 20 min**: Soaked, De-hulled, Boiled for 20 min and Dried Soya bean; **SDBDSB 40 min**: Soaked, De-hulled, Boiled for 40 min and Dried Soya bean; **SDDPRSB 10 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 10 min; **SDDPRSB 20 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 20 min; **SDDORSB 10 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 10 min; **SDDORSB 20 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 20 min; **SBDDSB 20 min**: Soaked, Boiled for 20 min, De-hulled, and Dried Soya bean; **SBDDSB 40 min**: Soaked, Boiled for 40 min, De-hulled, and Dried Soya bean; **BDDSB 20 min**: Boiled for 20 min, De-hulled and Dried Soya bean; **BDDSB 40 min**: Boiled for 40 min, De-hulled and Dried Soya bean; **ORSB 15 min**: Oven Roasted Soya bean for 15 min; **ORSB 30 min**: Oven Roasted Soya bean for 30 min; **PRSB 15 min**: Pot Roasted Soya bean for 15 min; **PRSB 30 min**: Pot Roasted Soya bean for 30 min

3.2.5.7 Foaming Capacity

The changes in foaming capacity (FC) of defatted and non-defatted soya bean flour samples during processing are presented in Figure 7. It can be observed that this parameter significantly ($p<0.05$) decreased with different treatments compared to the controls. The non-defatted flours were generally found to have a higher FC compared to the defatted ones. The significant decrease in FC upon treatments can be explained by the thermal denaturation of proteins which leads to the loss of functions. Akintayo *et al.* (1999) related good FC with protein flexibility which reduces the surface tension and highly order globular proteins which hinder surface alteration and decrease the foaming capacity. Flours are capable of producing foam through the active surface of the protein composing them. Soluble proteins can decrease the surface tension at the level of the interface between air bubbles constituting the foam and the environmental fluid leading to coalescence blockage. Additionally protein molecules can interact with each other to form a film with high flexibility of the interface air-liquid. As a result, the stability of the foam will increase (Adebowale and Lawal, 2003) as observed in this study.

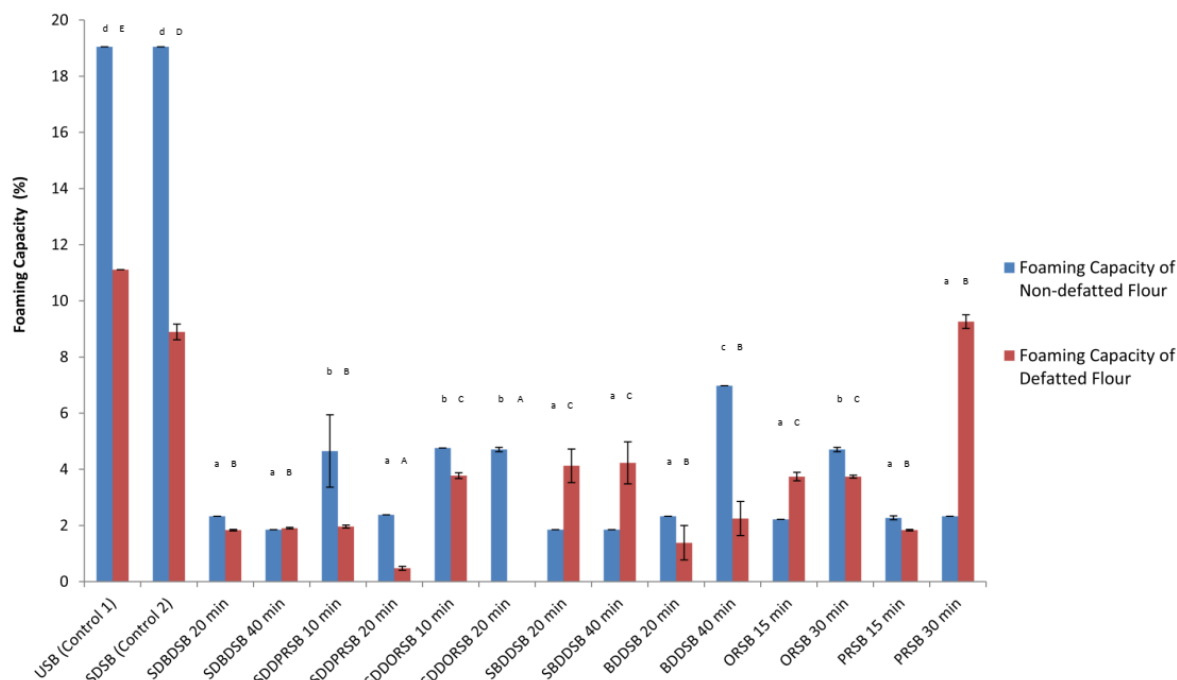


Figure 7. Changes in foaming capacity of non-defatted and defatted soya bean flour during processing

(a-d) values of water holding capacity of non-defatted flour with different superscripts are significantly different at $p < 0.05$. (A-E) values of water holding capacity of defatted flour with different superscripts are significantly different at $p < 0.05$. **USB (Control 1)**: Untreated Soya bean; **SDSB (Control 2)**: Soaked, De-hulled and Dried Soya bean; **SDBDSB 20 min**: Soaked, De-hulled, Boiled for 20 min and Dried Soya bean; **SDBDSB 40 min**: Soaked, De-hulled, Boiled for 40 min and Dried Soya bean; **SDDPRSB 10 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 10 min; **SDDPRSB 20 min**: Soaked, De-hulled, Dried and Pot Roasted Soya bean for 20 min; **SDDORSB 10 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 10 min; **SDDORSB 20 min**: Soaked, De-hulled, Dried and Oven Roasted Soya bean for 20 min; **SBDDSB 20 min**: Soaked, Boiled for 20 min, De-hulled, and Dried Soya bean; **SBDDSB 40 min**: Soaked, Boiled for 40 min, De-hulled, and Dried Soya bean; **BDDSB 20 min**: Boiled for 20 min, De-hulled and Dried Soya bean; **BDDSB 40 min**: Boiled for 40 min, De-hulled and Dried Soya bean; **ORSB 15 min**: Oven Roasted Soya bean for 15 min; **ORSB 30 min**: Oven Roasted Soya bean for 30 min; **PRSB 15 min**: Pot Roasted Soya bean for 15 min; **PRSB 30 min**: Pot Roasted Soya bean for 30 min

3.2.5.8 Protein Solubility

Among the parameters evaluated in the determination of the functional properties of foods especially legumes, protein solubility is the most complex because of its influence on other properties such as the foaming, emulsion and gelation capacities (Kinsella *et al.*, 1985). The influence of different processing methods on protein solubility of soya bean at different pH is presented in Table 6. Generally, protein solubility significantly ($p < 0.05$) decreases with processing time in treated samples compared to the controls. This can be attributed to protein denaturation during processing using these methods. The only methods and conditions with the best protein solubility were soaking, boiling for 20 and 40 min respectively, de-hulling and oven drying. The trend was almost the same with both defatted and non-defatted flours. The optimum pH range for their maximum solubility was between pH 1 - 12 which could be a proof that the proteins involved here are made up of acidic, neutral and basic amino acids. These results showed that soya bean flour can be used in the formulation or supplementation of different types of foods. The findings in this study were not in agreement with the report of Womeni *et al.* (2012) who showed that the highest solubility of *Rhynchophorus pheonicis* flour was at pH 7 - 9.

4. Conclusion

The objective of this study was to evaluate the effect of different processing methods on the nutritional and phytochemical properties of soya bean. The total phenolic content was found to significantly increase with roasting and decrease with boiling treatments. The processing methods applied significantly altered soya bean oil quality with treatment time. Soaking, boiling, de-hulling and drying (SBDDSB) considerably reduced the protein and carbohydrate contents of soya bean while soaking, de-hulling, boiling and drying increased its lipid content. The calcium, phosphorus, potassium, sodium and zinc contents expressively increased with the treatments, same with magnesium which exceptionally decreased with SDDPRSB, BDDSB and PRSB. Concerning anti-nutrients, phytate and oxalate meaningfully decreased with the treatments while the tannin increased. The flours exhibited good functional properties, except for emulsion and foaming capacities which significantly decrease with processing. Based on these, the nutritional and phytochemical and functional properties of soya bean make it to be a good ingredient for food formulation and preparation, both for nutritional and technological purposes.

Ethical Statement

This study does not involve human or animal testing.

Conflict of Interest

The authors confirm that they have no conflicts of interest with respect to this work.

Acknowledgement

Not applicable.

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