

# Impact of Thermal Processing on the Physicochemical Properties of Soybeans (*Glycine max*)

Oluranti M. Lawal<sup>1</sup>, Justina Y. Talabi,<sup>2</sup> and Victor N. Enujiugha<sup>1</sup>

<sup>1</sup>Department of Food Science and Technology, Federal University of Technology, Akure, Nigeria.

<sup>2</sup>Department of Human Nutrition and Dietetics, Afe Babalola University, Ado-Ekiti, Nigeria

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## CORRESPONDING AUTHOR

**Oluranti M. Lawal**

Department of Food Science and Technology, The Federal University of Technology, Akure, Nigeria  
lawal.om@futa.edu.ng  
+234-7030250802.

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## Abstract

Soybeans (*Glycine max*), a highly nutritious food, present inherent challenges in their raw form due to antinutritional factors, which require various processing methods that significantly alter their nutritional value and functional properties. This research examined the effects of different heat treatments, boiling, microwaving, and roasting, on soybeans' nutritional, antinutritional, mineral, and functional properties to provide insights into the impact of heat treatment methods on soybeans. All analyses were carried out according to standard procedures. Results showed that while crude protein generally decreased with processing (e.g., raw: 34.93 g/100 g; cooked: 24.81 g/100 g), crude fat (raw: 18.31 g/100 g; roasted: 27.72 g/100 g) and carbohydrate content significantly increased (raw: 39.27 g/100 g; cooked: 43.93 g/100 g). Crucially, processing markedly reduced significant levels of antinutritional factors present in raw seeds, such as tannins (0.29 to 0.25 mg/g), phytates (31.72 to 22.25 mg/g), oxalates (2.93 to 2.39 mg/g), and saponins (2.51 to 0.68%). Furthermore, cooked and microwaved soybeans exhibited higher concentrations of magnesium and potassium. Functional properties were also enhanced; roasted and microwaved seeds showed moderate bulk densities (0.69 and 0.67 g/cm<sup>3</sup>, respectively), and all treated samples demonstrated improved foaming capacity (3.85-7.69%). Roasted soybeans possessed the greatest oil absorption ability (2.25 g/g). Overall, the research indicates that thermal processing significantly improves soybeans' nutritional benefits and functional properties, while also reducing unwanted antinutritional compounds.

**Keywords:** Microwave cooking, Physicochemical characteristics, Protein, Soybeans, Toasting

## Introduction

Soybeans (*Glycine max* or *G. soja*) are a well-known agricultural product, esteemed for their affordable and readily available plant-derived protein. Every seed contains approximately 35% protein, while soybean meal contains a higher crude protein content—about 40-49% among other legumes and cereals. The oil content of soybean seeds ranges from 8.3 to 27.9% (Jin et al., 2023; Duan et al., 2023). The elevated protein and reduced starch levels make soybeans a superb protein source, especially advantageous for people with diabetes and those following low-carbohydrate diets. Soybean meal is a flexible, protein-rich alternative to meat utilised in various food items, such as infant nutrition. It can also be texturised to improve the cooked yield of items such as ground meat and bologna, an Italian soy-based sausage (Martin et al., 2010; Lehmalı & Jafari, 2019).

While soybeans provide a variety of uses, unrefined beans have an undesirable flavour and bitterness. Furthermore, they contain toxic proteins such as hemagglutinin and antitrypsin (Di He et al., 2024). These substances must be destroyed or inactivated to ensure palatability and digestibility for human and animal consumption (Zubko et al., 2022). The majority of soybean antinutritional and harmful components are thus greatly diminished or removed through processing.

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Soybeans undergo various dry and moist heat treatments during preparation. These culinary techniques are essential not only for enhancing texture and palatability but also for improving nutritional quality. Methods like steam cooking, boiling, and baking efficiently eliminate the antinutritional effects found in unprocessed soybeans (Lehmali & Jafari, 2019). Commonly consumed varieties of processed soy comprise soy beverage, soy protein, soy powder, bean curd, texturised vegetable protein (TVP), utilised in various vegetarian and meat substitute items, soy lecithin, soybean oil, and tempeh. Soybeans are also the main component in soy sauce (shoyu).

Numerous culinary uses of soybean products capitalise on the functional properties of soybean proteins. These characteristics include their ability to combine, thicken, froth, generate coatings, create gels, take in water and/or fat, and develop meat-like consistencies (Zhijie et al., 2023). These functional characteristics are inherently connected to the protein's amino acid composition and sequence (primary structure), as well as its spatial arrangement and molecular interactions (secondary and tertiary structures). Soybean protein items with distinctive functional characteristics are essential in developing "processed foods" (FAO, 1974; Duan et al., 2023). However, the processing techniques deployed, particularly heat application, may alter these functional properties or reduce the antinutrients present in soybeans. This study thus specifically examined the impact of diverse heat treatments on soybeans' chemical makeup and functional characteristics.

## Materials and Methods

### Materials

Mature, high-quality (improved variety TGX-1485-1D) soybean seeds were obtained from King's market in Akure, Ondo State, Southwest Nigeria.

### Sample preparation

The soybean seeds were sorted and cleaned, then immersed in a 0.07% concentration of sodium bicarbonate solution for 8 hours to aid dehulling and lower phytic acid content, before undergoing dehulling and washing (Rijal & Adhikari 2012). After that, the batch was split into four parts of 1 kg each for various heat treatments, and the 4<sup>th</sup> was retained as raw untreated for control.

### Thermal treatment of soybean seeds

The first portion was roasted at 100 °C for 3 hours in the oven, then dried in the cabinet dryer at 60 °C for 8

hours. The second portion was cooked in boiling water at 110 °C for 1 hour. The third portion was microwaved at 619W power output in the microwave oven (Hisense H20M0BS1) for 30 minutes. All heat-treated samples and a raw, unprocessed control were then dried and ground into flour using a hammer mill (HTSCSFHM000018) and kept in polyethene bags for later analyses.

### Proximate assessment of unprocessed and thermally treated soybean flour

The proximate composition of the soybean flour samples was assessed following the AOAC (2019) methods. Crude protein content was determined from total nitrogen by applying a conversion factor 6.25. Carbohydrate content was calculated by subtraction and represented as nitrogen-free extractives (NFEs). Ash content was assessed gravimetrically by burning samples in a muffle furnace at 550 °C overnight. Seed oil was obtained with n-hexane utilising a Soxhlet extractor. Crude fibre was established through acid digestion.

### Mineral components of the samples

Mineral analysis was carried out according to a method outlined by Enujiugha et al. (2003). For microelements (Fe, Cu, and Zn), 25 g of each seed flour specimen (unprocessed and processed) was utilised, whereas 10 g was allocated for macro nutrients (K, Ca, and Mg). All assessments were conducted in sets of three. Samples were incinerated at 550 °C for five hours in a muffle furnace. The resulting white ash was dissolved in 2 mL of a 1:1 v/v blend of nitric and perchloric acids. Following the evaporation of the surplus acid, the remaining residue was dissolved in deionised water and adjusted to final volumes of 50 mL for microelements and 100 mL for macroelements. Lanthanum chloride was included in both the acidic solutions of the residues and the reference solutions at a final concentration of 1% (w/v) to avoid possible interference during the measurement of Ca and Mg. Flame photometry was utilised for K, and Atomic Absorption Spectrometry (AAS, Pye Unicam model SP9) was employed for Zn, Fe, and Cu.

### Determination of functional properties of soybean samples

The functional properties examined, namely, water and oil absorption capacity, foaming capability, and bulk density, were determined using methods described by Lawal and Enujiugha (2016). Refined soybean oil with a 0.9 g/cm<sup>3</sup> density was employed for the oil absorption

capacity assessment. Each 5.0 g flour sample was completely blended, while checking the pH, with 25 mL of deionised water or oil in 50 mL centrifuge tubes. The mixtures were vortexed intermittently for 30 min at room temperature (25 °C) and subsequently centrifuged at 12,000 rpm for 30 min at 25 °C. The volume of the decanted supernatant was measured, and the capacities for absorbing water and oil were determined. Packed bulk density was defined as the mass per unit volume of an adequately compacted 12 g sample in a 25 mL graduated cylinder. All samples were analysed in triplicate.

### Determination of antinutritional factors of the samples

The antinutritional factors examined in the seed flour specimens comprised tannins (in the form of tannic acid), phytic acid, phytin-P (phytin-phosphorus), oxalate, and saponins. Phytates were determined according to the method of Ramadan (2012). Five milligrams of the sample were mixed, cured for five hours and filtered. Aliquots of 2500 mL of the filtrate in a conical flask were added to 5 mL of 0.30% ammonium thiocyanate, and the mixture was titrated with standard iron (III) chloride solution to a persistent brownish yellow colouration that persisted for 4 min. Tannin content was established utilising the adapted vanillin-HCl technique. Analyses were conducted on samples previously dried in a ventilated oven at 55 °C for 24 h. Catechin (Sigma Chemical Co., St Louis, MO) was used as the reference standard, and tannin concentration was expressed in g of catechin equivalent.

Oxalates were determined by soaking 1 g of the sample in 75 mL of 1.5 M H<sub>2</sub>SO<sub>4</sub> for one hour, and were filtered. Aliquots of 25 mL of the filtrate were titrated against 0.1 M KMnO<sub>4</sub> until a pink colour was obtained, and the oxalates were measured by the spectrophotometric technique (AOAC, 2019).

Saponin content was established using the approach Enujiugha et al. (2014) outlined. Saponins were extracted from 0.5 g of the sample using 5 mL of an 80% methanol solution. The sample was mixed and centrifuged. The saponin extract (0.2 mL) was combined with 80% methanol (0.3 mL), 8% vanillin (0.5 mL), and 72% sulfuric acid (5 mL) solutions, then incubated at 60 °C for 10 min. The absorbance values were recorded at 544 nm, employing an 80% methanol

solution as the reference. The results were reported in percentages.

### Statistical Analysis

The statistical significance of observed differences among the means of experimental data replicates was assessed using analysis of variance (ANOVA). Means were separated using Duncan's multiple range test. All analyses were performed using the Statistical Software for the Social Sciences (SPSS) 10.0 computer program.  $P < 0.05$  was applied to establish significant differences.

## Results and Discussions

### Chemical composition of soybean samples

The proximate analysis of raw and heat-processed soybeans is presented in Table 1. The findings revealed that the samples were high in protein. In particular, roasting and microwave cooking enhanced the crude protein levels of the seeds. The roasted sample had 37.79 g/100 g, and the microwaved sample had 36.62 g/100 g. These figures are considerably higher than those documented for other comparable legume seeds, such as *Phaseolus vulgaris* (17.75%), *Pentaclethra macropphylla* (33.42%), *Parkia biglobosa* (29.06%), *Sphenostylis stenocarpa* (20.67%), and mung beans (23.56%) (Adamu et al., 2015).

On the other hand, cooking decreased the protein levels in the soybeans. This finding is consistent with results from Ojinnaka & Ojimelukwe (2013) regarding castor seeds (*Ricinus communis*) processed into ogiri, and by Arueya, Owoseni, & Olatoye (2017) on African oil bean seeds. The reduction in protein could be due to the soluble proteins dissolving into the processing water and/or the effects of denaturation (Yousefi & Abbasi, 2022).

The unprocessed soybean sample demonstrated a considerable oil content of 18.31% when compared to pulses such as cowpea (1.6%), chickpea (5.6%), and pigeon pea (1.2%). However, it was less than groundnut (45.3%) and peanut (50.0%) (Popoola et al., 2023). Compared to the unprocessed sample, an increase ( $P < 0.05$ ) was observed in the crude fat levels of roasted, cooked, and soybeans that had undergone microwave treatment.

The noted elevated oil content is typical of tropical oilseeds. The rise in oil content post-processing can be linked to eliminating moisture and intensifying dry matter during drying processes before size reduction.

Sylvia et al. (2023) noted a comparable pattern, indicating that processing probably improves oil extraction. For instance, the elevated oil content of African oil bean seed makes it a significant source of vegetable oil for both dietary and industrial purposes (Mbah et al., 2018).

Raw soybean seeds contained a fibre level of 1.38 g/100 g, which was not altered by cooking, roasting, or microwave processing. This fibre level is less than what was noted for chickpea (10.3%), broad bean (8.5%), peas (5.9%), mung bean (5.0%), adzuki beans (3.9%), lentil (3.2%), peanut (3.0%), groundnut (2.1%) (FAO, 1974; Popoola et al., 2023). As a result, soybeans might not be regarded as an essential source of nutritional fibre.

The ash content in raw soybeans was 6.11 g/100 g, significantly higher than the levels found in cooked (3.33 g/100 g), microwaved (4.41 g/100 g), and roasted (4.76 g/100 g) soybeans. Ash content is vital for several reasons, including its application as an indicator of food quality for animal nutrition. The diminished values in processed samples may result from the extraction of ash-containing elements during processing (Alarape et al., 2024).

The carbohydrate level in raw soybeans was 30.27 g/100 g. The values for roasted (28.45 g/100 g) and microwaved (30.68 g/100 g) samples demonstrated decreased carbohydrate levels, while the prepared sample increased to 43.93 g/100 g. Nonetheless, the carbohydrate content of soybeans is still significantly greater than that of groundnuts (21.6%), yet lower than that of chickpea (61%), lentil (62%), pea (60%), and

broad bean (55%) (Bonku & Yu, 2020; Popoola et al., 2023).

### Effect of Processing on Antinutrient Levels in Soybeans

The impact of various processing methods on the levels of phytic acid, phytate phosphorus, tannins, oxalates, and saponins in soybeans is key to its functionality. Table 2 shows significant reductions ( $P < 0.05$ ) in phytic acid and phytate phosphorus after cooking, roasting, and microwaving. This is consistent with the findings of Haji (2021), linking a decrease in antinutrients in legumes to cooking/ boiling. The reduction in phytic acid is likely due to its solubility in water during soaking and cooking and the action of endogenous phytases (Sylvia et al., 2023). However, it is essential to note that phytic acid can paradoxically increase the bioavailability of proteins and minerals in some cases (Schmidt & Oliveira, 2023). The high level of phytic acid (as phytin-P) in roasted soybeans is a concern, as this form is largely inaccessible to humans and can inhibit the absorption of other essential minerals (Haji, 2021).

Raw soybeans contained 0.29 g/100 g of tannins, which decreased with all heat treatments. A high tannin content in raw seeds contributes to astringency, an unpleasant taste caused by tannins binding to proteins in saliva and mucosal membranes (Naik, 2010). The reduction in tannins after processing is attributed to both their heat-sensitive nature and their solubility in water, which causes leaching during cooking. Boiling, in particular, effectively reduces tannin levels in other

**Table 1: Proximate composition of the soy flour (g/100 g Dry wt)**

| Component     | Raw                     | Roasted                 | Cooked                  | Microwaved              |
|---------------|-------------------------|-------------------------|-------------------------|-------------------------|
| Crude Protein | 34.93±0.11 <sup>c</sup> | 37.79±0.01 <sup>a</sup> | 24.81±0.03 <sup>d</sup> | 36.62±0.02 <sup>b</sup> |
| Crude Fat     | 18.31±0.02 <sup>b</sup> | 27.72±0.09 <sup>a</sup> | 26.79±0.11 <sup>a</sup> | 27.02±0.05 <sup>a</sup> |
| Ash           | 6.11±0.01 <sup>a</sup>  | 4.76±0.03 <sup>b</sup>  | 3.33±0.01 <sup>d</sup>  | 4.41±0.02 <sup>c</sup>  |
| Crude Fibre   | 1.38±0.01 <sup>a</sup>  | 1.28±0.00 <sup>a</sup>  | 1.14±0.03 <sup>a</sup>  | 1.27±0.01 <sup>a</sup>  |
| Carbohydrate  | 39.27±0.12 <sup>b</sup> | 28.45±0.09 <sup>d</sup> | 43.93±0.03 <sup>a</sup> | 30.68±0.11 <sup>c</sup> |

Values are means of triplicate samples. Means with different superscripts in the same row show a significant difference ( $P < 0.05$ ).

**Table 2: Concentrations of antinutritional components in the soybean flour samples**

| Samples    | Tannin (g/100 g)       | Phytin Phosphorus (Mg/g) | Phytic Acid (Mg/g)      | Oxalate (Mg/g)         | Saponin (%)            |
|------------|------------------------|--------------------------|-------------------------|------------------------|------------------------|
| Raw        | 0.29±0.01 <sup>a</sup> | 8.94±0.10 <sup>a</sup>   | 31.72±0.11 <sup>a</sup> | 2.93±0.05 <sup>a</sup> | 2.51±0.02 <sup>a</sup> |
| Roasted    | 0.26±0.01 <sup>b</sup> | 7.72±0.04 <sup>b</sup>   | 29.19±0.12 <sup>b</sup> | 2.47±0.03 <sup>b</sup> | 1.25±0.01 <sup>b</sup> |
| Cooked     | 0.26±0.00 <sup>b</sup> | 6.27±0.07 <sup>c</sup>   | 22.25±0.17 <sup>d</sup> | 2.57±0.02 <sup>b</sup> | 0.73±0.01 <sup>c</sup> |
| Microwaved | 0.25±0.01 <sup>b</sup> | 7.78±0.18 <sup>b</sup>   | 27.60±0.14 <sup>c</sup> | 2.39±0.01 <sup>b</sup> | 0.68±0.00 <sup>d</sup> |

legumes, such as common beans (Chisowa, 2022), winged beans, and lima beans (Sylvia et al., 2023). The decrease in tannins is beneficial as it enhances protein digestibility and improves the overall nutritional value of the soybeans.

Additionally, processing methods like cooking, roasting, and microwaving were also found to lower the levels of oxalates and saponins (Schmidt & Oliveira, 2023).

### **Mineral content of raw and processed soybean flour**

The mineral composition of raw, cooked, roasted, and microwaved soybean samples is shown in Table 3. The magnesium concentration in raw soybean (46.06 mg/g) increased with cooking (79.38 mg/g) and microwaving (49.42 mg/g), whereas roasting reduced the magnesium concentration, probably as a result of elevated temperatures. Roasting and microwaving also reduced the calcium content of unprocessed soybeans from 15.48 to 12.77 mg/g and 13.48 mg/g, respectively, but increased with cooking (31.41 mg/g). It was also observed in this study that raw soybeans had 84.92 mg/g of potassium, which improved with cooking (148.96 mg/g) and microwaving (97.17 mg/g), but decreased with roasting (83.29 mg/g).

The zinc level in raw soybeans (2.5 mg/g) was diminished by roasting (1.44 mg/g) and microwaving (1.71 mg/g) but increased with cooking (4.04 mg/g). Zinc plays an essential role in various physiological processes, with a suggested daily intake of no less than 40 mg Zn per kg of diet (dry matter) for humans (Patil, 2023) translates to a daily consumption of 20 mg of bioaccessible zinc for adults. Cooked soybean, having a zinc concentration of 4.04 mg/g, would serve as an excellent source of dietary zinc (Karkle & Bei, 2010). The iron level notably ( $P < 0.05$ ) diminished after roasting and microwave cooking but improved with traditional cuisine. Thus, roasted and microwaved soybeans are considered inadequate sources of dietary iron. Cooking slightly enhanced the amount of copper, but only a negligible amount was found in roasted and microwaved soybeans.

### **Functional characteristics of raw, cooked, roasted, and microwaved soybeans**

The functional characteristics of raw and processed soybeans are presented in Table 4. The Water

Absorption Capacity (WAC) of raw soybeans was 2.00 g/g and showed no change due to roasting. Cooking enhanced the WAC, whereas microwave cooking reduced it. For comparison, lima bean flour had a water absorption capacity of 1.93 g/g when subjected to a temperature of 87 °C (Palupi et al., 2021).

The Oil Absorption Capacity (OAC) of the unprocessed sample was 1.35 g/g, which increased with roasting (2.25 g/g) and cooking (1.80 g/g). This result is similar to the study by Nguyen (2015), which reported OAC of 0.69-1.12 g/g for heat-treated soybeans. Soybeans with high oil absorption capacity are desirable for the cold meat industry, where the protein can bind the fat and water in these products. At the same time, differences in WAC can be linked to fluctuations in protein components, pH, and ionic strength, as WAC serves as a valuable metric for flours suitable for water-based food formulations, particularly those used in dough, sausages, soups, and gravies. In contrast, OAC determines the efficiency of a protein source as a meat extender or substitute (Kakar et al., 2022).

The initial bulk density of unprocessed soybeans was 0.71 g/cm<sup>3</sup> and decreased due to roasting, cooking, and microwaving. This measurement was not as favourable as the mean bulk density of 1.79 g/cm<sup>3</sup> reported by Getaneh & Gemed (2024) for six soybean varieties. A high bulk density provides packaging benefits by enabling a larger amount to fit within a fixed volume; the processed samples exhibited a decrease in bulk density (Lin, Wang & Selomulya, 2022).

The foaming ability of raw soybeans was 1.96%, and it was increased by cooking (5.88%), roasting (3.85%), and microwaving (7.69%). Foam is a two-phase system of air bubbles divided by a thin liquid film. The capability of a protein to create foam and maintain its stability relies on elements like the type of protein, the level of denaturation, pH, and whipping methods (Luca et al., 2021). Essential criteria for an effective foaming agent encompass quick absorption at the air-water boundary, prompt conformational alteration and restructuring at the interface, and creating a unified viscoelastic film through intermolecular interaction (Tsaliki et al., 2002). The initial two criteria are vital for optimal foam production, whereas the third is essential for maintaining foam stability (Deotale et al., 2023).

**Table 3: Certain mineral content of soybean flour (mg/g)**

| SAMPLES    | Mg    | Ca    | K      | Zn   | Fe   | Cu   |
|------------|-------|-------|--------|------|------|------|
| RAW        | 46.06 | 15.48 | 84.92  | 2.58 | 2.69 | 0.05 |
| ROASTED    | 42.90 | 12.77 | 83.29  | 1.44 | 0.35 | -    |
| COOKED     | 79.38 | 31.41 | 148.96 | 4.04 | 5.42 | 0.08 |
| MICROWAVED | 49.42 | 13.48 | 97.17  | 1.71 | 0.14 | -    |

**Table 4: Certain functional characteristics of the untreated and processed samples**

| Samples    | Bulk density (g/cm <sup>3</sup> ) | Water Absorption Capacity (g/g) | Oil Absorption Capacity (g/g) | Foaming Capacity %     |
|------------|-----------------------------------|---------------------------------|-------------------------------|------------------------|
| Raw        | 0.71±0.02 <sup>a</sup>            | 2.00±0.06 <sup>b</sup>          | 1.35±0.03 <sup>c</sup>        | 1.96±0.01 <sup>d</sup> |
| Roasted    | 0.69±0.01 <sup>b</sup>            | 2.00±0.01 <sup>b</sup>          | 2.25±0.11 <sup>a</sup>        | 5.88±0.11 <sup>b</sup> |
| Cooked     | 0.63±0.06 <sup>d</sup>            | 3.50±0.04 <sup>a</sup>          | 1.80±0.00 <sup>b</sup>        | 3.85±0.07 <sup>c</sup> |
| Microwaved | 0.67±0.03 <sup>c</sup>            | 1.00±0.01 <sup>c</sup>          | 1.35±0.11 <sup>c</sup>        | 7.69±0.01 <sup>a</sup> |

Values are means of triplicate samples. Means with different superscripts in the same column show a significant difference ( $P < 0.05$ ).

## Conclusion

Soybeans exhibited varying nutritional, antinutritional, and functional properties when subjected to heat treatment. Considering the chemical composition of the soybean samples, roasting enhanced the crude protein levels, while microwaving soybeans also showed a moderate increase. In assessing the decrease of antinutrients, cooking demonstrated advantages over alternative heat treatments. Additionally, cooking gave the most advantageous mineral composition and the most beneficial functional qualities. Therefore, cooking was the most efficient heat treatment, producing the highest quality soybeans. Consequently, it can be determined from this study that cooking is the most efficient thermal processing technique for enhancing the overall quality of soybeans.

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