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Impact of Hulling and Heat Treatment on the Physicochemical Properties, Bioactivity and Bioavailability of Iron and Zinc of the G196 Soybean Variety Produced in Burkina Faso

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Abstract

This study delved into the impact of hulling and two types of heat treatment on the physicochemical, bioactive properties and bioavailability of the G196 soybean produced in Burkina, in order to not only find the optimal conditions for pre-treatment of seed, but also to guide their use in food formulations. Standard analytical methods were used for physicochemical and biochemical analyses. The results showed an increase in ash content by 0.04% as a result of seed shelling, while steaming led to a significant decrease in ash with a reduction rate by 0.06%; 0.08%; 0.25% after 20min, 40min and one hour, respectively. An average increase in total dry materials by 0.03% and reduction in moisture by 6.33% were observed after one hour of roasting. Additionally, shelling and steaming increased total carbohydrate contents. Roasting and steaming caused a significant reduction in protein, but an increase was observed after hulling. Carbohydrate levels decreased over the course of three roasting times. Regarding bioavailability, the zinc content improved after 40 minutes of roasting. Shelling also reduced the phytate content by 11.89%, while steaming significantly reduced the phytate, resulting in a drop in the phytate content by 17.18%; 18.02% and 19.71% after twenty, forty minutes and one hour, respectively. A significant reduction in phytate content by 26.64% after 40 minutes, and 46.46% after one hour was observed during heat treatment by roasting.

Keywords: soybeans, hulling, steam cooking, roasting, physicochemical properties, bioavailability, food quality, Burkina Faso

1. Introduction

Soybeans are of East Asia origin and have been grown in China for millennia (Shea et al., 2020). It is one of the most important annual crops in the world (Jähne, 2020). Its global production is estimated at more than 330 million tonnes per year with an increase of around 5% each year (FAO, 2021). In Burkina Faso, Glycine max (L.) Merrill is the fourth most popular cash crops, after cotton, peanuts and sesame, (MAAAH 2016). Widely used by the food industry, it is an economically important crop that provides high quality oil and protein (Luthria et al., 2018; Pimentel et al., 2021). Due to its versatility as an industrial raw material, this legume has high potential for commercial cultivation (Ali, 2019). It produces 70.86% of the world's supply of vegetable protein meals and 28.88% of the world's vegetable oil supply (Lin et al., 2022). Soybean has become a major industrial food crop in West Africa Sinclair et al. (2014). soybean seeds are an excellent source of essential nutrients, which also provide with proteins, carbohydrates, dietary fiber, vitamins and minerals for human and animal nutrition. It is an excellent source of complete protein, highly digestible with a rate ranging from 92% to 100% and containing bioactive compounds beneficial to health (Chen et al., 2012; Chatterjee, 2018).

Used for the production of various food items, soybeans cannot be eaten raw due to the presence of

anti-nutritional factors that can reduce the bioavailability of minerals and protein absorption due to their chelating properties (Samtiya et al., 2020). To make it edible and to benefit from its many nutrients, pre-treatments are applied during its transformation into food formulations. The traditional pre-treatment methods include hulling, roasting and steaming, which are used during the production of derived foods. Roasting is a food processing process that involves exposing food to direct fire or a suitable heat source. It uses dry heat. Steaming, on the other hand, is a less common heat treatment method in grain processing. Dehulling involve removing the whole seed shells by mechanical processes (Egounlety, 2003; Bunea and Pop, 2021). Many authors reported that the nutritional value of seeds can be significantly altered during these thermal and physical pre-treatments (Asrat et al., 2019; Djikeng et al., 2022). These treatments can lead to a considerable reduction in the nutritional and functional compounds of soybeans. The influence of these treatments on the nutritional value, the bioavailability of minerals as well as the bioactive properties depends on parameters such as temperature and duration of treatment. It is therefore important to find a balance to preserve nutrients while improving the bioavailability of minerals and minimizing the loss of heat-sensitive nutrients. To achieve this, optimizing pre-treatment methods could improve the nutritional value of soy-based foods. Unfortunately, there is very little data on the influence of traditional pre-treatments such as hulling, roasting and steaming soybeans. In addition, no study on these aspects has been carried out on soybeans grown in Burkina Faso. The objectives of this study were therefore to find optimal soybean pre-treatment conditions optimizing the nutritional value during the production of soybean-derived foods, incorporating the studied pre-treatments.

2. Materials and Methods

2.1 Plant Material

The plant material consisted of soyabeans seeds of the G196 variety (Glycine max) harvested in 2019 from producers certified by the Institute of Environment and Agronomic Research (INERA) in Manga (11°39′48″ N, 1°04′12″ W), in the Centre-North region. The influence of individual farmers' farming practices was minimized by constructing a composite sample using the cluster sampling method (Hameed: Taherdoost, 2016).

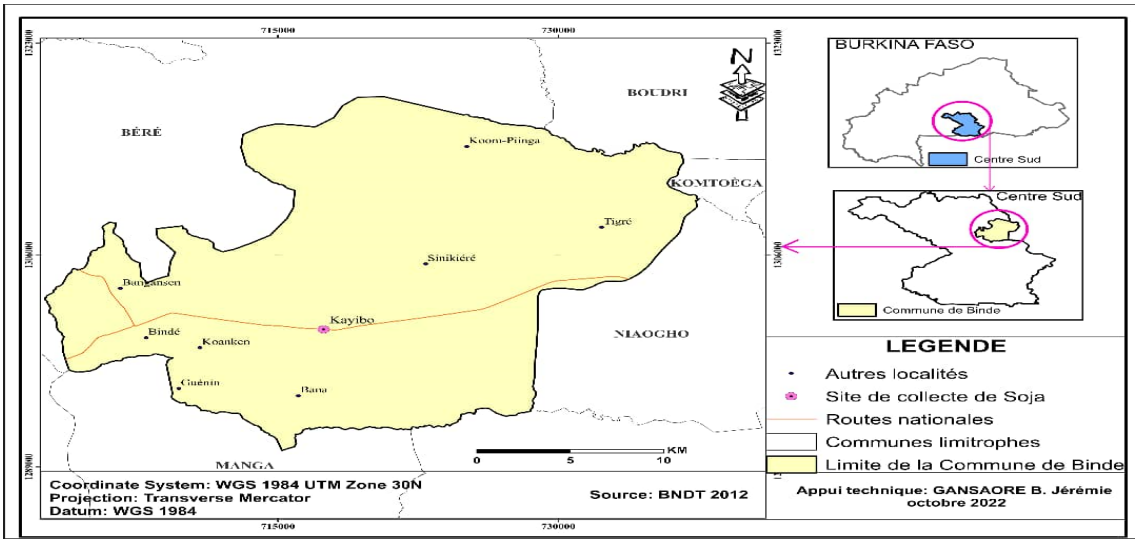

Figure1. Mapping of Soybean collection site

Figure 2. Photo of soybean seeds of variety G196

2.2 Seed Pretreatment Methods

2.2.1 Roasting

The soybeans were sorted, washed, drained and dried at room temperature for 72 hours according to the method used by Andrade et al. (2016) with some minor modifications. Then, they were divided into 9 trials of 500g each. Three roasting times were tested: 20 minutes (T 20), 40 minutes (T 40) and 60 minutes (T 60), at a temperature of 120°C. Before starting roasting, the roaster is pre-heated and roasting begins when the temperature of the seeds inside the roaster reaches 120°C.

2.2.2 Shelling and Steaming

Hulled soybeans are obtained by mechanically removing the hulls by using a mortar. Then, these seeds are dried in a dryer at a temperature of 40°C for 72 hours. They are then winnowed and crushed in an electric crusher. Steam cooking was carried out using a couscous machine, following the method described by Dida and Urga (2018). Steaming lasted 20 minutes, 40 minutes or 1 hour, from the moment the water started to boil (T0) with the escape of the water vapor.

Figure 3. Steps in the hulling and steaming process (ouédraogo et al., 2024)

a: seeds being shelled; b: hulled seeds; c: hulled seeds for steam cooking

2.2.3 Seed Pretreatment Flowchart

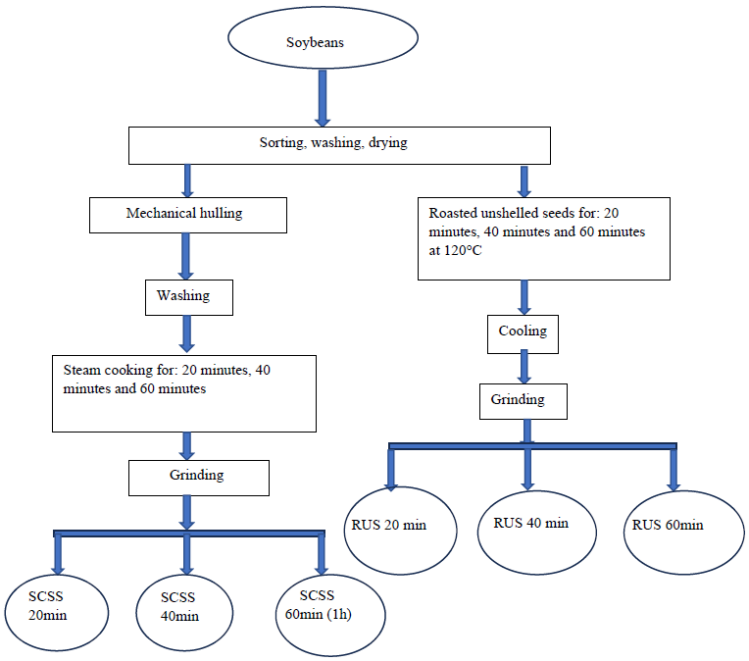

Figure 4. Seed pre-treatment flowchart (ouédraogo et al., 2024)

RUS: Roasted unshelled sample, SCSS: Steam-cooked shelled sample.

2.2.4 Preparation of Soy Flour

The roasted seeds were cooled before grinding while the steamed soybean seeds of the G196 variety were dried, cleaned and then dried in an oven at 40°C. All of the pre-treated seeds are then crushed using an electric grinder. The flour obtained is then sieved using a 300 µm sieve then stored in plastic bags and kept in the refrigerator at 5°C for physicochemical and biochemical analyses.

2.3 Physicochemical and Biochemical Analysis Methods

2.3.1 Dry Matter, Moisture and Ash

The water and dry matter content was determined by drying at 105°C for 24 h in an oven according to standard NF V 03-707. The ash content was determined using a muffle furnace at a temperature of 550°C for 6 hours according to the standard.

2.3.2 Dosage of Total Sugars, Fat and Protein Content

The total soluble carbohydrate content was determined using the phenolic method with some modifications. Absorbances are read on the spectrophotometer at 490 nm. Glucose was used as standard to construct a linear plot ($y= 0.0107x + 0.9804$; $R^2 = 0.998$). The fat content of the samples was determined by the standard Soxhlet extraction method as described by (Luque de Castro and Priego-Capote (2010) according to NF V 03-905, 2009). The determination of the total soluble protein content was performed by the spectrometric method described by Bradford (1976) with slight modifications Bolek et al. (2016). Samples (500 mg) of soybeans flours were homogenized in 10 mL of 0.1 M NaCl, and the whole stirred for 5 h at150 rpm/min at 25°C. The extract was collected after centrifugation at 4,400 rpm for 30 min at 4°C. To 50 µL of each extract, 250 µL of Bradford reagent was added. After 2 min of incubation, the absorbances are read at 595 nm. A standard curve ($y =1.3138x + 0.0119$; $R^2 =0.999$) was built using BSA as standard. The energy value was estimated using the Atwater coefficients and the calorific value of the sample was evaluated using the method of (Merill, 1976). Energy value = P x 4 Kcal + G x 4 Kcal + L x 9 Kcal = X kcal /100 g. P, C and L are respectively the proportions of proteins, carbohydrates and fasts.

2.3.3 Determination of Total Phenolic Compounds

The determination of total phenolic compounds was performed using the Folin-ciocalteu reagent method described by (Dicko et al., 2002) with some minor modifications. To do this, 100 µl of extract were mixed with 500 µl of the Folin-ciocalteu reagent and 400 µl of sodium carbonate (Na_2CO_3) at 7.5 % (m/v). The mixture was shaken and incubated in the dark at room temperature for two hours and the absorbance was read read at 760 nm by a spectrophotometer (Epoch; BioTeK). The phenolic content was determined a gallic acid calibration curve under the same conditions. The results were expressed in milligram gallic acid equivalent per 100 mg of dry sample (mg EAG/100 mg/DM).

2.3.4 Assay of Total Flavonoids

The determination of total flavonoids was carried out according to the colorimetric aluminum trichloride ($Alcl_3$) method adapted by (Arvouet-grand et al. (1994) Aluminum trichloride ($Alcl_3$) reacts with the flavonoid present in the sample, forming a yellow complex. The intensity of this coloring is measured at a wavelength of 415 nm, and is proportional to the concentration of flavonoid. To do this measurement, a volume of 125 µl of each extract (at a concentration of 1 mg/ml) is mixed with 125 µl of 2% (m/v) aluminum trichloride. The mixture is shaken and incubated in the dark, at room temperature, for 30 minutes. A blank is also made by replacing aluminum trichloride with 95% methanol. The absorbance is then measured at 415 nm using a spectrophotometer (Epoch; BioTeK). To quantify the flavonoids, quercetin is used as a standard in the establishment of a calibration curve, with concentrations ranging from 0 to 100 µg/L. The results are expressed in equivalent milligrams of quercetin per 100 milligrams of dry plant material, with reference to this calibration curve under the same conditions.

2.3.5 Determination of Phytate Content

Phytates were measured based on the method suggested by Latta and Eskin (1980); (Vaintraub and Lapteva, 1988). This method involves extraction of phytates using hydrochloric acid, followed by precipitation of phytic phosphorus as iron phytates using iron trichloride ($FeCl_3$). Then, the formation of a colored complex (pink-purple) in the presence of sulfosalicylic acid is measured to quantify the phytates. In 10 ml tubes, 250 mg of sample and 5 ml of 2.4% HCl were added successively and then left at room temperature for two hours with mechanical stirring. The tubes were then centrifuged for 30 minutes at 6,000 rpm at 20°C. The supernatant obtained in each tube was divided into two Eppendorf tubes, with 1 ml per tube, and stored in the refrigerator for later analyses. A mixture of 750 µl of supernatant diluted 1/25 and 250 µl of Wade reagent was prepared, then

centrifuged for 10 minutes at 10,000 rpm at 20°C. Then, the solution was transferred to a 1.5 ml cell. The phytate contents were determined by measuring the absorbance of the solution at 500 nm relative to a blank (distilled water). Optical densities between 0.3 and 0.5 were used for the analysis. A calibration range established from phytic acid solutions was used to estimate the phytic acid concentration of the samples using the following equations:

OD 500 nm: a [Phytic acid] + b After determining the value of parameters "a" and "b", the phytic acid content of the sample is deduced according to the formula:

$$\text{Phytic acid (mg/g MS)} = [(\text{OD 500nm} - b) \times D] / (a \times \text{MS})$$

With: [Phytic acid]: concentration of phytic acids (µg/ml) D: sample dilution factor a: slope of the regression line (always negative) b: ordinate at the origin of the line Phytic acid: quantity of phytic acids in mg/g DM. Dry matter of the sample to be analyzed (mg)

2.3.6 Determination of Mineral Content

The mineral content (K, Mg, Na, Fe, Mn, Zn,) of soybean seeds was determined using a flame atomic absorption spectrophotometer according to the AOAC method described by Jorhem and Engman (2000). The elements to be measured were dissociated in a flame and placed in a ground state which allows them to absorb light at characteristic wavelengths.

3. Statistical Analyzes

Statistical analysis of the data was carried out using XLSTAT software (Addinsoft, 2021). It included an analysis of variance (ANOVA) with a Tukey test at a threshold of 5% to compare the means. Results were presented as mean ± standard error (SD) of the mean.

4. Results

4.1 Variation in the Physicochemical Composition of Whole, Hulled, Steamed and Roasted Seeds

Significant variations ($p < 0.05$) in ash, dry matter as well as moisture content of whole, hulled, steamed hulled and roasted seeds at different temperatures were observed in this study. As shown in Table 1, a 0.04% increase in ash was observed in hulled seeds compared to unhulled seeds. Hulling of soybean seeds had no significant effect on total dry matter (TDM) and moisture content of seeds. The results indicate a significant reduction in ash with reduction rates of 0.06%, 0.08% and 0.25% respectively for hulled seeds steamed for 20 minutes, 40 minutes and one hour. After one hour of steaming, an average increase of 0.03% in DMC (Dry Matter Content) was observed, while moisture decreased by 6.33%. Roasting results in a significant drop in ash and dry matter (DM) content as a function of time with a rate of 0.053%; 0.19%; 0.17 for ash content respectively after 20 minutes, 40 minutes and 1 hour. Regarding TMS, an increase by 1.37% was observed after 20 minutes, then 1.78% after 40 minutes to one hour of roasting. The variations observed were significant depending on the duration of the heat treatment applied. Cooking has an impact on dry matter content. However, duration has no influence. Table 1 shows the effect of hulling, steaming and roasting on the physicochemical composition of whole, hulled, hulled steamed and roasted seeds.

Table 1. Physico-chemical characteristics of shelled, steamed and roasted samples

	Samples	Asch (g/100gMS)	Moisture (g/100gDM)	Dry matter content (g/100g)
Unshelled sample	US	5.040 ± 0.65^{b}	4.95 ± 0.01 ^{a}	95.04 ±1.95^{b}
Shelled sample	SS	5.08 ±0.75 ^{a}	4.89 ± 1,07^{a}	95.10 ± 2,5^{b}
Steam-cooked shelled sample	SCSS 20min	5.02 ± 0.00 ^{c}	5 .02 ± 0.01^{a}	95.49 ± 0.01 ^{a}
	SCSS 40min	5.00 ± 0.05 ^{c}	5.00 ± 0.07 ^{a}	94.91 ± 0.04 ^{a}
	SCSS 1hour	4.811± 0.02 ^{d}	4.58± 0.08 ^{b}	95.41 ± 0.06 ^{a}
Roasted unshelled sample	RUS 20 min	5.09 ± 0.01 ^{b}	3.58 ± 0.01 ^{b}	96.41 ± 0.16^{b}
	RUS 40 min	5.23± 0.04 ^{a}	3.16 ± 0.01 ^{c}	96.82 ± 0.04 ^{a}
	RUS 1 hour	5.21± 0.84 ^{ab}	3.08 ± 0.87 ^{c}	96.829±1.78 ^{a}
	Pr > F	0	0	0
	Significant	Yes	Yes	Yes

US: Unshelled sample, SS: Shelled sample, RUS: Roasted unshelled sample, SCSS: Steam-cooked shelled sample; DM: Dry matter.

4.2 Variation of Macronutrients of Shelled and Roasted Seeds Over Time

Based on the results of the analysis, it was found that hulling and heat treatments had a significant impact on the total carbohydrate contents of the samples studied. In general, a decrease in the total carbohydrate content was recorded during roasting. No significant differences were observed between carbohydrate contents for roasting times ranging from 20 to 40 minutes and from 40 minutes to one hour. However, a significant drop in carbohydrate content was observed between 20 minutes and one hour of roasting. When it comes to steaming, different trends were observed depending on the duration. After 20 minutes of steaming, no significant difference was recorded in carbohydrate content. However, a significant increase in the content was observed after 20 minutes and one hour of cooking respectively. In conclusion, shelling and steaming for 40 minutes to one hour can increase the carbohydrate content. Steaming for 20 minutes has no effect on carbohydrate content. Concerning the protein content, the study revealed a significant increase in protein contents after hulling, however, it decreased significantly depending on the duration of steaming and roasting. Analysis of variations in soybean macronutrient content revealed a loss of protein and total carbohydrate contents during roasting with reduction rates of 1.51%; 2.67%; 10.46% for proteins and 1.32%; 2.05%; 2.86% for carbohydrates after 20 min, 40 min and one hour respectively compared to the content of the unprocessed seed. As the cooking and roasting time increases, the loss increases. As for lipids, hulling did not influence the rate of extraction of lipid content. A significant increase in lipids was observed with roasted seeds. Thus, a significant increase in lipid levels was recorded after 20 min of extraction. From 40 minutes onwards, the extraction yield remained stable. The rate of lipid extraction in cooked seeds after 20 and 40 minutes was not influenced on the one hand and compared to unprocessed seeds. However, from steaming for 1 hour the rate increases significantly.

Table 2. Nutritional value of shelled, steamed and roasted samples

	Lipid (g/100gDM)	Protein (g/100gDM)	Carbohydrate (g/100gDM)
US	20.056 ± 1.93 ^{fg}	38.681 ± 2.75 ^{b}	17.88 ± 3.14 ^{cd}
SS	20.25± 1.78^{ef}	39.664±3.45 ^{a}	18.46 ± 1.14^{c}
SCSS 20min	21.121±0.4^{b}	37.171±0.3^{e}	16.569±0.8 ^{de}
SCSS 40min	21.670±0.2 ^{a}	36.010 ±0.5^{de}	15.83±0.6 ^{ef}
SCSS 1h	21.673±0.5 ^{a}	28.22± 0.3 ^{gh}	15.028 ± 0.9 ^{fg}
RUS 20 min	20.60 ±0.12 ^{df}	36.4± 0.32^{d}	18.2± 0.14^{bc}
RUS 40 min	20.682 ±0.18 ^{df}	34.28 ± 0.27 ^{ef}	18.493 ± 0.15 ^{b}
RUS 1 h	21.087±0.13 ^{cd}	29.4± 0.42^{fg}	19.97± 0.31 ^{a}
Pr > F	0	0	0
Significance	Yes	Yes	Yes

US: Unshelled sample, SS: Shelled sample, RUS: Roasted unshelled sample, SCSS: Steam-cooked shelled sample; DM: Dry matter.

NB: The averages of the same column not sharing any letter in common are significantly different

4.3 Energy Value of Hulled, Steamed and Roasted Samples

The applied pre-treatments had a significant impact on the energy value of the samples. The shelled sample (SS) presented a maximum energy value of 414.823±1.45 kcal/100g, followed by unshelled sample (US) with 406.80±12.45 kcal/100g. No significant differences were observed between the unshelled sample and the shelled sample steamed for twenty minutes in terms of energy value. The duration of the treatment had no effect on the energy value before sixty minutes (one hour) of roasting. However, as early as sixty minutes (one hour), an energy loss of 9.27% was observed compared to untreated seeds. The assessment of the drop in energy value showed a loss of 9.13% energy from forty to sixty minutes of roasting and a loss of 8.54% from 40 to 60 minutes of steaming. Steaming resulted in a significant reduction in energy, which increased with increasing cooking time. The energy losses recorded after 20, 40 and 60 minutes of steaming were 2.65%, 4.29% and 6.643%, respectively. Compared to roasting, steaming showed a more pronounced decrease in energy.

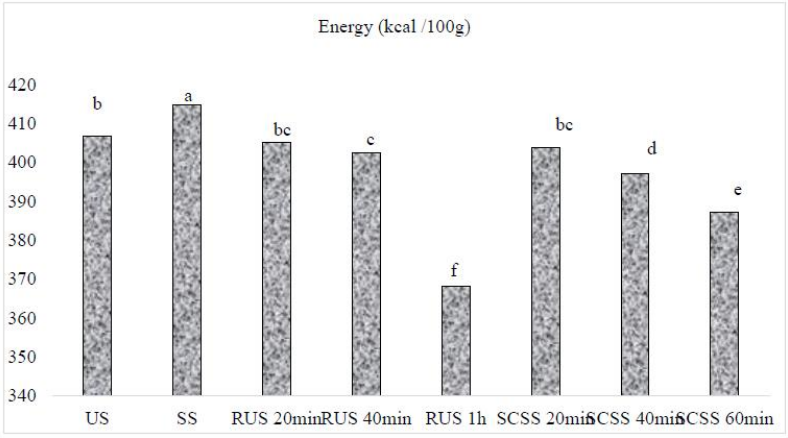

Figure 5. Energy value of hulled, steamed and roasted samples

US: Unshelled sample, SS: Shelled sample, RUS: Roasted unshelled sample, SCSS: Steam-cooked shelled sample; DM: Dry matter.

NB: The means of each series not sharing any letter in common are significantly different (P <0.05).

4.4 Impact of Roasting Time on Bioactive Compounds

After roasting whole soybean seeds, the results showed a significant difference ($P < 0.05$) in total phenolic compounds and flavonoids content compared to their respective controls. The results showed a significant increase in polyphenol content while flavonoid content decreased with a rate of 0.4%, 0.28%, 2.86% respectively after 20min, 40min and one hour of roasting.

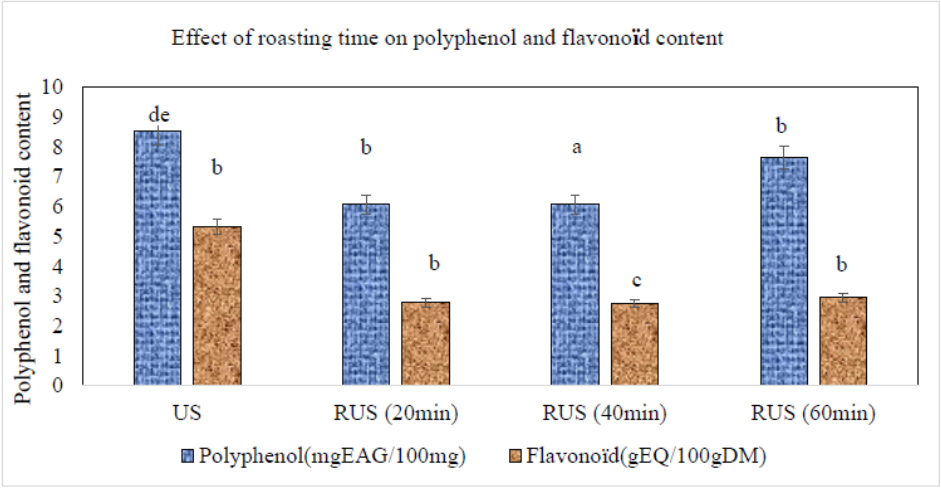

Figure 6. Effect of roasting time on polyphenol and flavonoid content

US: Unshelled sample, RUS: Roasted unshelled sample

4.5 Effects of Hulling and Steaming Time on Bioactive Compounds

Shelling and cooking time did not show a significant effect on polyphenol content. However, a loss of flavonoid content was observed, with reduction rates of 2.89%, 6.96% and 6.77% at 20 minutes, 40 minutes and one hour of cooking respectively.

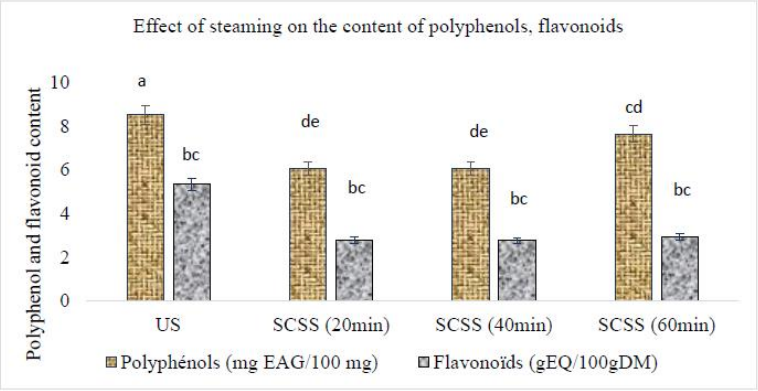

Table 7. Effect of steaming on polyphenols and flavonoids content

US: Unshelled sample; SCSS: Steam-cooked shelled sample

4.6 Influence of Hulling, Steaming and Roasting on Phytate Content

The results of the study show that hulling resulted in an 11.89% drop in phytate content. Additionally, steaming the hulled seeds reduced phytate by 17.18% after 20 minutes, 18.02% after 40 minutes, and 19.71% after one hour of cooking. Regarding roasting, a significant decrease in phytates was observed, with a reduction of 17.47% after 20 minutes of heat treatment, 26.64% after 40 minutes, and 46.46% after 1 hour of roasting.

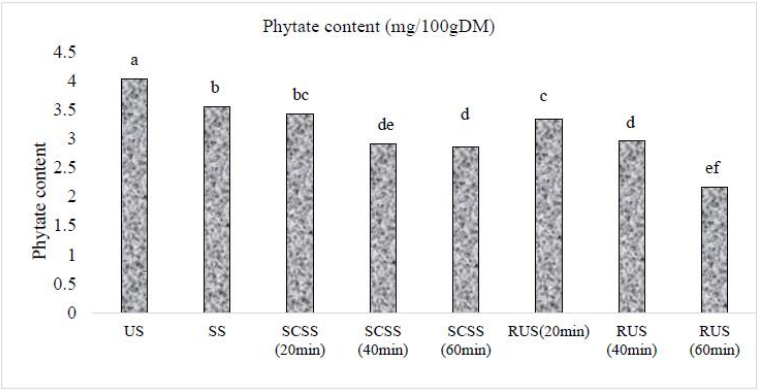

Figure 8. Variations in phytate content in hulled, steamed and roasted seeds

US: Unshelled sample, SS: Shelled sample, RUS: Roasted unshelled sample, SCSS: Steam-cooked shelled sample; DM: Dry matter.

4.7 Influence of Roasting on the Bioavailability of Iron and Zinc

After hulling, an increase in iron (Fe) and zinc (Zn) level was observed. Between 20 and 40 minutes of cooking, iron and zinc level remained stable. However, a significant drop was noted after one hour of cooking.

Table 3. Effect of hulling, roasting and steaming on the phytate content and bioavailability of iron and zinc

Settings	US	SS	SCSS 20min	SCSS 40min	SCSS 60min
Fe (mg/100gDM)	7.49±1.4 ^{b}	7.53±.,42 ^{a}	7.431±0.005^{c}	7.472±0.005 ^{c}	7.183±0.000 ^{d}
Zn (mg/100gDM)	7.57±0.78 ^{b}	8.371±1.14^{a}	7.187±0.06^{c}	7.23±0.04^{c}	4.680±0.013^{d}
Pr > F	0	0	0	0	0
Phy/Zn	0.53±0.03 ^{b}	0.42±0.03 ^{c}	0.47±0.03 ^{c}	0.40 ±0.03 ^{c}	0.60 ±0.03 ^{a}
Phy/Fe	0.47 ± 0.03 ^{b}	0.53±0.01^{a}	0.46±0.01 ^{b}	0.38±0.08 ^{c}	0.39±0.03 ^{c}
Pr > F	0	0	0	0	0

US: Unshelled sample, SS: Shelled sample, RUS: Roasted unshelled sample, EDCV: Steam-cooked shelled sample; DM: Dry matter.

NB: The average of the same column not sharing any letter in common are significantly different

4.8 Influence of Roasting on the Bioavailability of Iron and Zinc

The Fe and Zn content was not influenced during the treatment. Shelling had no effect on the bioavailability of iron and zinc. The bioavailability of iron decreased after one hour of roasting while the bioavailability of zinc improved from 40 min of roasting.

Table 4: Effect of roasting on mineral content and their bioavailability

Settings	US	RUS 20min	RUS 40min	RUS 60min
Fer (mg/100gDM)	7.497±1.14[a]	7.431±0.005[a]	7.465±0.005[a]	7.472±0.005[a]
Zinc (mg/100gDM)	7.57±0.78[a]	6.557±0.065[a]	6.567±0.069[a]	6.703±0.088[a]
Pr > F	0	0	0	0
Significance	Yes	Yes	Yes	Yes
Phy/Fe	0.53±0.01[a]	0.449±0.071[a]	0.397±0.056[a]	0.290±0.013[b]
Phy/Zn	0.53±0.01[a]	0.509±0.03[a]	0.45±0.01[b]	0.323±0.02[c]
Pr > F	0	0	0	0
Significance	Yes	Yes	Yes	Yes

US: Unshelled sample, RUS: Roasted unshelled sample.

5. Discussion

The treatments applied resulted in a change in the physicochemical and biochemical composition of the soybean seed. Soybean hulling involves removing the outer husk. This is a treatment of the seeds most often carried out before other pre-treatments such as steaming or roasting. Indeed, the hulled seeds were richer in ash, carbohydrates, proteins in Fe, Na and Zn with improved bioavailability while the unshelled seeds were characterized by a richness in total polyphenols. The ash levels found in this study are similar to those reported in the literature. The ashes provide the body with minerals which are essential elements for the proper functioning of the body, bind to proteins, giving metalloproteins which are important in metabolism (Élie, 2022). Sodium (Na) contributes to the basic acid-base balance. Zinc is an anti-inflammatory and antioxidant agent. As for iron, it is a component of hemoglobin. The high Fe and Zn content of hulled seeds give hulled seed flour important nutritional properties. Soy carbohydrates are criticized for being difficult to digest and causing flatulence. Its increase in hulled seeds calls for their pre-treatment during the production of derived foods. Protein content in shelled seeds was the highest at 39.66 g/100 g DM compared to roasted and steamed seeds. In support of our findings, Halas et al. (2020) found that hulling improves the protein content of soybeans. Choi et al. (2023) noted a17.69% increase in crude protein in faba bean seeds after shelling. The high levels of protein in hulled seeds could be explained by the fact that hulling removes certain undesirable compounds while concentrating beneficial nutrients in the seed. Indeed, soy proteins are recognized for their functional properties and can reach a digestibility of 95% according to Harle (2020). They are also rich in health-promoting bioactive peptides. Shelling could therefore be a necessary pre-treatment of soybeans in formulations requiring high protein contents. Polyphenol contents were reduced by 1.2% after shelling. Several studies have shown that hulling leads to a significant drop in polyphenol content, up to a 50% loss. Such a decrease could be explained by the preferential localization of these bioactive compounds in the seed envelope which was removed during hulling. These phytochemicals are of very significant therapeutic interest. They are known as having antioxidant properties, which allows them to play a role in the treatment of inflammatory, cardiovascular or neurodegenerative diseases Pandey and Rizvi (2009) ; Tsao (2010). Soybeans shelling should therefore be avoided when formulating food in which phenolic compounds are compounds of interest. A significant drop in moisture content was recorded during roasting. This is due to the application of heat to the seeds, which would cause the water contained in it to evaporate. These results are in agreement with Gonzalo (2000) who states that roasting reduces the moisture content of the initial seed by 30%. A 20-minutes roast can be applied for better preservation of soybeans intended for food. Ashe decreased by 0.053%, 0.19%, 0.17% after 20 minutes, 40 minutes, and one hour of roasting, respectively. The decrease in ash content after hulling soybeans could be explained by the fact that ash is mainly made up of inorganic minerals such as calcium, magnesium, potassium and phosphorus, which are present in the outer layer of the soybean's seeds. An increase in oil content of 1.37% after 20 minutes of roasting and then 1.78% after 40 minutes and one hour shows that roasting soybeans could improve the extraction rate of soybean oil. An increase in oil content after roasting was reported for millet, maize and sesame seeds respectively by (Oboh et al. (2010) and Makinde and Akinoso (2014). It can therefore be applied to improve the oil extraction efficiency in food industries. Roasting significantly reduce ($p < 0.05$) total sugar levels with a reduction rate of 32%; 2.05%; 2.86% after 20 minutes, 40 minutes and one hour respectively. These reductions could be induced by the

formation of complexes with sugars during the Maillard reaction. Protein saw a decrease of 1.51%; 2.67%; 10.46% after 20 minutes, 40 minutes, and one hour. However, soy protein is known have important nutritional properties and health benefits. The reduction in proteins during heat treatment is associated with their denaturation. This decrease in protein content could therefore be due to the breaking of intramolecular bond, the deployment and aggregation of soybean protein molecules. However, this thawing improves the nutritional value by facilitating access to enzymes, and by modifying the refractory properties of soybeans into digestible proteins. The assessment of the decrease in energy value showed an energy loss of 9.13% from 40 to 60 minutes of roasting and a loss of 8.54% from 40 to 60 minutes of steaming. The energy losses recorded after 20, 40 and 60 minutes of steaming were 2.65%, 4.29% and 6.643%, respectively. Compared to roasting, steaming showed a more pronounced decrease in energy. Shelling led to an increase in energy value. Changes in energy value depending on the treatments could be attributed to the mode of heat exposure. Regarding bioactive compounds, the total polyphenol content which was 9.71645±1.02 g GAE/100 g DM before roasting increases from 10.937 ±0.03 g GAE/100gDM after 20min, an increase of 1.22 g GAE/100gDM and 11.768 ± 0.318 g GAE/100gDM after 40 min, an increase of 2.052 g GAE/100gDM compared to the initial content of the whole soybean seed. The increase in content could result from the release of bound polyphenols or Maillard reaction products that are formed during roasting. Dewanto et al.(2002) explained the increase in polyphenols during roasting by the disruption of membranes and cell walls, which releases the soluble phenolic content of insoluble esters. Hyo et al. (2011) reported that the phenolic content of roasted small black soybeans was higher than that of unroasted small black soybeans. After one hour of roasting, the polyphenol content in the seed drops considerably by 1.32 mg GAE/100gDM. After 40 minutes of roasting, there is an increase followed by a decrease after one hour. This result corroborates with that of the company that found an increase in the polyphenol content after 15 minutes of roasting at 230°C but a clear drop after 18 minutes of heat treatment. The loss of phenolic compounds during heat treatment has been reported by some previous studies (Lemos 2012). This loss was attributed to thermal decomposition and heat-induced oxidation of the compounds as a function of temperature and time. The rate of flavonoids reduction was 0.4%, 0.28%, 2.86% after 20 minutes, 40 minutes and one hour, respectively. Losses gradually increase depending on the roasting time. These results are in agreement with Zhang et al. (2010) who showed that as the duration of heat treatment increases, flavonoid degradation is greater. Gujral et al.(2013) attributed the decrease in flavonoid during roasting to heat-induced oxidation and degradation. Furthermore, cooking celery in the presence of water at a temperature of 50°C for 90 seconds caused a loss of approximately 22% in total flavonoids in a study carried out by Choi et al. (2006). Phytic acid is a chelator of iron and zinc, in humans, and can cause malnutrition by disrupting their bioavailability. Steaming the hulled seeds revealed a drop in phytate contents from 40 minutes to one hour with respective reduction rates of 17.18% after 20 minutes of cooking, 18.02% after 40 minutes. Heating therefore made it possible to reduce the phytic acid content, which will increase the bioavailability of zinc and iron in the grains. An improvement in bioavailability phy/Fe, phy/Zn as a function of cooking time has been found according to Song et al. (2022). The 17.18% drop in phytates after 20 minutes of steaming would therefore improve the bioavailability of iron and zinc in soy-derived foods. Consequently, the phy/Fe and phy/Zn ratios show that bioavailability has been improved. So, from 20 minutes, steaming can reduce the phytate content in soybeans. Roasting and steaming are two types of heat treatment that can improve the bioavailability of minerals in soybeans during the production of derived foods. But since roasting is more aggressive on heat-sensitive minerals, the use of steam cooking would allow better retention of essential minerals.

6. Conclusion

The study showed that seed hulling led to an increase in ash, carbohydrate, protein and iron, sodium and zinc content, with improved mineral bioavailability. However, a significant decrease in polyphenols in hulled seeds requires for optimization of this soybean processing step. Roasting resulted in a significant decrease in moisture and ash content, as well as a reduction in total sugar and protein levels. Roasting has therefore had a significant impact on the nutritional value and food applications of soybeans by altering its physicochemical properties. A twenty minutes roast preserves the protein content better while a 40-minutes roast improves the polyphenol content. Regarding bioactive compounds, the polyphenol content has increased compared to whole soybeans, while flavonoids decreased. The influence of the evaluated heat treatments had a significant impact on the bioavailability of zinc and iron. Steaming would be better indicated with an optimal duration in order to maximize the retention of essential minerals and thus avoid their excessive loss during soybean processing.

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Abreviations

Phy	Phytate
Zn	Zinc
Fe	Fer
Min	Minute
Shelled sample	SS
Unshelled sample	US
Steam-cooked shelled sample	SCSS
Steam-cooked shelled sample for 20 minutes	SCSS (20min)
Steam-cooked shelled sample for 40 minutes	SCSS (40min)
Steam-cooked shelled sample for 60 minutes	SCSS (60min)
Roasting unshelled sample	RUS
Roasting unshelled sample for 20 minutes,	RUS (20min)
Roasting unshelled sample for 40 minutes,	RUS (40min)
Roasting unshelled sample for 60 minutes,	RUS (60min)

Conflict of interest

The authors declare that there is no conflict of interest.

Authors' contributions

Elisabeth Rakisewendé Ouédraogo, Raymond Poussian Barry, and Salamata Tiendrebeogo, contributed to all sections and writing of the article. Elisabeth Rakisewendé Ouédraogo contributed to the design of the article Conceptualization, data curation, formal analysis, methodology, validation, visualization, writing - original draft, writing - review and editing. Raymond Poussian Barry contributed to study selection and data extraction, writing - review and editing. Salamata Tiendrebeogo and Fréderic Anderson Konkobo contributed to the data analysis, interpretation and writing of the article. Sandrine Zongo and Edwige Noelle Roamba contributed to the sampling and correction of the manuscript. Kiessoum and Mamoudou Hama Dicko: Contributed reagents and materials.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Obtained.

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The Publication Ethics Committee of the Canadian Center of Science and Education.

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The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

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No additional data are available.

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