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Research Article
Impact of Hydrothermal Techniques on the Chemical Components of *Mallotus subulatus*

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Abstract

Background and Objective: *Mallotus subulatus* is an underutilised hard-to-cook legume in South West Nigeria. The aim of this study was to investigate the effects of four hydrothermal techniques (atmospheric boiling, atmospheric steaming, pressure boiling and pressure steaming) on the cooking time and chemical components of the seed after soaking to varying hydration levels. **Materials and Methods:** The seeds were soaked at varying hydration levels and then subjected to thermal processing to determine the effect of four hydrothermal techniques, on mineral elements present in the *Mallotus subulatus* seeds. The data were analyzed by using SAS (ver. 15). All data were subjected to Analysis of Variance [ANOVA] and the significant differences were determined at $p<0.05$. The means were separated using Duncan's Multiple Range Tests. **Results:** Soaking of the seed prior to thermal processing decreased cooking time. Highest reduction of 80.18% in cooking time was observed when the seed was processed by pressure boiling. Hydrothermal processing methods caused significant reduction in the nutrients. Boiling at elevated pressure had better retention of nutrients. Increase in hydration level resulted in better conservation of nutrients. Crude protein content of the raw sample (20.97%) decreased by 4.63% at 100% hydration level when the seed was boiled at elevated pressure. The processing methods caused significant decreases in phytic acid, saponin and tannin, however, trypsin inhibitor was eliminated. **Conclusion:** The results showed that processing of the seeds at high hydration levels followed by boiling at elevated pressure caused the lowest reduction in cooking time and better retention of nutrients. The study will encourage adaptation of this lesser known legume and hence solve the problem of protein energy malnutrition.

Key words: *Mallotus subullatus*, underutilised legume, nutrients, antinutritional components, hydrothermal techniques

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Legumes are considered as important sources of dietary protein in many nations of the world and especially in the developing countries. Legumes are used as a source of protein for animal and human[1]. The need for protein by a large percentage of the world population, particularly those of the developing nations has not been met, although many efforts have been made to provide the world population with protein rich diets[2]. Protein from animals are superior to those of plants because they contain essential amino acids but have failed to meet the protein need of the majority of the world population because animal proteins are expensive and scarce[3]. Many efforts have been made to find alternative sources to animal protein. This include increase in the production and utilisation of legumes which are believed to contain appreciable quantity of high quality protein. In recent times, consumption of legumes has been on the increase. This is because legume seeds have been reported to be good sources of nutrients. They are recommended as health promoting foods by health organisations and dieticians. Legumes have been reported to reduce the incidences of cardiovascular diseases, cancers and type II diabetes[4,5]. Moreover, frequent consumption of legumes may be of assistance in weight management[1,6]. In spite of the advantages of legumes as good sources of beneficial nutrients, legumes often contain anti nutritional components which interfere with the digestive processes and prevent efficient utilization of nutrients. These anti nutritional components include enzymes inhibitors, cyanogens, haemaglutinin, phytates, saponin and tannin. Antinutrients in many common legumes could easily be removed or reduced below the level of toxicity or antimetabolic activity by subjecting them to various processing techniques such as soaking, boiling and germination[7,8]. The problem of prolong cooking constitute a major hinderance to the utilisation of many underutilised legumes.

Mallotus subulatus (*Pepelupe funfun*) is one of the underutilised legumes in South West Nigeria. This specie of legume is not available in much commercial quantity but is found with peasant farmers in villages where it is planted mainly for subsistence purposes. Apart from the presence of anti nutritional factors, *Mallotus subulatus* is a hard-to-cook legume. In this study, efforts have been made to investigate the effects of hydrothermal processing methods on the nutrients and anti nutritional components of *Mallotus subulatus* with the aim of enhancing its utilisation. Provision of information on the effects of soaking and different hydrothermal processing methods on the nutrients and anti nutritional components, it is hoped, will prefer solution to the problem of prolong cooking. This could also widen dietary pattern and other forms of utilization thereby solving the prevalent problem of Protein Energy Malnutrition (PEM) in many developing regions of the world.

MATERIAL AND METHODS

Material: The seeds of *Mallotus subulatus*, the white variety locally called *pepelupe funfun* (Plate 1), were procured from local market in Saki (8.67°N, 3.40°E), Saki West Local Government Area of Oyo State, Nigeria. The seeds were dry-cleaned thoroughly and the immature seeds and extraneous particles were removed. The cleaned seeds were stored at room temperature until further analysis.

Legume seed processing: Whole seeds of the legume were subjected to the following processing methods: Soaking, atmospheric boiling, boiling in pressure cooker, atmospheric steaming and steaming at high steam pressure.

Soaking and determination of soaking time: Soaking and determination of hydration rate of the legume were carried out. The method described by Xu and Chang[9] was adopted and modified for use. The legume sample (500 g) was cleaned and soaked in 2500 cm^3 of distilled water in a glass beaker at ambient temperature (23-28°C) for up to 24 h. Water absorption (increase in moisture) of the legume during soaking was measured hourly for the initial 0-6 h and every 2 h. The soaked legume was blotted with a woollen hand towel at appointed time to remove excess water before weighing and returning into soaking water. Moisture content of soaked legume was calculated. Furthermore, the water absorption curve was plotted to show the kinetic increase of the moisture content with time. The plateau phase of water absorption curve was defined as 100% hydration level.

Plate 1: *Mallotus subulatus* (*Pepelupe funfun*) white specie

Soaking time of the legume with desired hydration level was calculated through polynomial equation of respective water absorption curves.

For the subsequent boiling and steaming experiments, the legume was pre-soaked to the desired hydration levels of 10, 25, 50, 75 and 100% by controlling soaking time. The soaked legume was then boiled or steamed by the methods below: the raw sample without soaking (0 % hydration level) was processed to serve as control.

Boiling at Atmospheric Pressure (BAP): The boiling of the legume sample was done using a domestic cooker. Pre-soaked legume (500 g) with varying hydration levels was boiled separately in distilled water. Determination of cooking time was performed by tactile method[10]. After boiling treatment the seeds were drained and both the cooking water and the drained seeds were cooled in plastic containers. The cooked legume and cooking water were dried at 45-50°C using cabinet drier. The dried samples were stored in cellophane bags prior to analysis.

Boiling at Elevated Pressure (BEP): Boiling at elevated pressure was done using a pressure cooker (Binatone PC-5001) at about 80±8 kPa. Pre-soaked legume (500 g) with varying hydration levels was put each in distilled water in a glass flask covered with aluminium foil. The flask containing the legume was quickly brought to boiling on a hot plate. The legume sample with boiling water was placed into pre-heated pressure cooker with boiling water and the lid was locked. The cooking time was counted from when steam began to spurt out from pressure regulator on the lid. Cooking time was determined by tactile method[10]. When the legume has been cooked to the desired cooking time, the pressure cooker was then removed from the hot plate and the pressure released. The boiled legume sample was cooled to ambient temperature (23-28)°C and dried at 45-50°C using a cabinet drier. The dried sample was then stored in cellophane bags container before analysis.

Steaming at Atmospheric Pressure (SAP): Steaming and determination of steaming time were carried out at normal atmospheric pressure using steam cooker. The pre-soaked legume sample (500 g by weight) with varying hydration levels was placed each on a tray in the steam cooker covered with lid and were steamed over boiling water. Steaming time was determined by tactile method[10]. After the steaming process, legume was cooled and dried at 45-50°C in a cabinet drier. The dried samples were then stored in cellophane bags before analysis.

Steaming at Elevated Pressure (SEP): Steaming at elevated pressure was performed using a pressure cooker (Binatone PC-5001) at about 80±8 kPa. Pre-soaked sample (500 g by weight) of varying hydration levels was placed each on a tray in a pressure cooker and steamed over boiling water under selected high pressure (80±8 kPa). Steamed seeds were placed in plastic containers, cooled and then dried at 45-50°C in a cabinet drier. The dried sample was stored in cellophane bags before analysis.

Proximate composition: Proximate analysis was carried out on the legume sample of *Mallotus subulatus* before and after hydrothermal processing. The moisture content was determined using air-oven method at 105°C. The crude protein, crude fibre, crude lipid and total ash contents were determined following the standard methods[11]. The total carbohydrate content was determined by difference.

Determination of mineral elements: Atomic absorption spectrophotometer-Buck 205, was used to determine some mineral elements-Iron, Zinc, Magnesium, Calcium, Sodium, Phosphorus and Potassium. The pulverized sample was weighed and ashed in a muffle furnace at 550°C until properly ashed. The ash was dissolved in 100 cm^3 solution of HCL (10% v/v) which was subsequently used in mineral content determination. Hollow cathode lamp of each element supplied resonance line radiation. Standard calibrations were employed in the analysis[11].

Determination of Trypsin Inhibitor Activity (TIA): The trypsin inhibitor activities were determined using the procedure of Smith *et al.*[12]. Benzoyl-DL-arginine-P-nitroaulidehydrochloric (BAPNA) manufactured by Zefa Laboratory Service, Germany was used as substrate. Crystalline porcine pancreatic trypsin (trypsin ZF 93615.0025) 40 mg (Boehinge Bellane loives) manufactured by Zefa Laboratory Service, Germany and dissolved in 0.001M HCl such that standard trypsin solution contained 40 µg trypsin.

Extraction of trypsin from legume sample: N-hexane was used to defat 1 g of finely ground and sieved sample for 3 h. The sample was mixed with 50 cm^3 of 0.01 M NaOH and the pH was adjusted to 9.5 using 0.1 M HCl or 0.1 M NaOH. The mixture was macerated in a blender for 2 min and centrifuged at 100 rpm for 10 min. The extract from each sample was diluted with distilled water to obtain a dilution whereby 1 cm^3 extract produced trypsin inhibition activity of between 40 and 60% and such dilution was used.

Trypsin inhibitor activity determination: Each sample dilution was used with BAPNA substrate and trypsin solutions at 37°C[13]. The reaction was allowed to take place in a water bath (Uniscope model SM 902B) for 10 min and their absorbance read at 410 nm against each sample bank.

Trypsin inhibitor was calculated as:

$$TIA = \frac{2.632 \times D \times A_1}{S} = \frac{mg\,pure\,trypsin}{g\,sample}$$

Where:

D = Dilution factor
A_1 = Change in absorbance (pure trypsin and sample extract)
S = Sample mass (g)

Determination of tannin content: The tannin content was determined by modifying the procedure of Markker[14]. The seed flours were defatted using diethyl ether, ground and sieved through 500 µm sieve. About 0.2 mg of the defatted flour was extracted with 10 cm^3 of 70% aqueous acetone for 2 h in a water bath (Uniscope model SM 902B) at 30°C. The extract was centrifuged at 3500 rpm for 20 min and 0.05 cm^3 of the supernatant was used. Increasing concentration of standard tannic acid was prepared and 0.5 cm^3 folin-Ciocalteu reagent was added and their absorbance measured at 725 nm against distilled water using a spectrophotometer (Model-Buck 205). The absorbance of the various tannic acid concentrations was used to obtain a regression equation that was used to determine tannic acid in each sample extract. The regression equation was:

$$Y = 0.021X-0.01$$

Where:

Y = Absorbance
X = Tannic acid (µg)

Tannic acid from each sample was determined and expressed as mg g^{-1} of the flour sample.

Extraction of saponin: The procedure of Markker and Becker[15] was modified for use. About 0.5 g of the dried, grinded sample was defatted with 10 cm^3 of petroleum ether by shaking for 4 h. It was then was extracted twice with 5 cm^3 of aqueous methanol by shaking on an orbit shaker for 4 h. The extract was stored in the dark at 40°C.

Total saponin content determination: Spectrophotometric method was used to determine the total saponin content[16]. About 0.1 cm^3 of the legume extract, 0.5 cm^3 of freshly prepared vanillin solution (in ethanol), 0.4 cm^3 of 80% methanol solution and 50 cm^3 of 72% sulphuric acid were mixed together thoroughly in an ice water bath. The mixture was warmed in a water bath at 60°C for ten min and then cooled in ice cold water. Absorbance at 544 nm was recorded against the reagents blank with a UV-visible spectrophpotometer (UV 160 Shimadzu). The results were expressed as mg of soya saponin equivalent g^{-1} of legume (mg of SSE g^{-1}) on a dried weight basis from a standard curve of different concentration of crude soya saponin (contained a minimum of 80% saponin, Sigma-Aldrich) in aqueous methanol.

Extraction of phytic acid: Phytic acid was extracted according to the method of Gao *et al.*[17]. About 0.5 g of the raw dried sample deffated with 10 cm^3 of petroleum ether by shaking for 4 h and then the residue was extracted with 10 cm^3 of 24% HCL by shaking on the orbit shaker for 6 h. The extract was stored at 4°C in the dark prior to further analysis.

Phytic acid determination: Phytic acid was determined using the colourimetric (Wade reagent) method described by Gao *et al.*[17]. with slight modification. About 0.1 cm^3 of the extract was diluted by 29 cm^3 of distilled water and then 3 cm^3 of this diluted sample was combined with 1 cm^3 of freshly prepared Wade reagent (0.03% $FeC_{l3}.6H_2O$+Sulfosalicylic acid) in a 15 cm^3 tube. The contents were thoroughly mixed and centrifuged at 5500 rpm at 10°C for 10 min. A series of calibration standards containing 0, 5, 10, 20, 25, 75 or 100 mg cm^{-3} of phytic acid were prepared by diluting 10 mg cm^{-3} of phytic acid stock solution with distilled water. Absorption of colour reaction products for both samples was read at 500 nm on a UV Spectrophotometer (UV160 Shimadzu) against water as blank. The results were expressed as milligrams of phytic acid per gram of legume (mg g^{-1}) on a dry weight basis.

Statistical analysis: All experiments and analyses were carried out in triplicates and results expressed as Mean±SD deviation. Statistical Analysis Software (Version 15) was used for the statistical analysis. All data were subjected to Analysis of Variance [ANOVA] and the significant differences were determined ($p<0.05$). The means were separated using Duncan's Multiple Range Tests.

RESULTS AND DISCUSSION

Cooking time as influenced by hydrothermal processing methods: The effects of soaking followed by different hydrothermal processing methods at varying hydration levels on the duration of cooking for the samples are presented in Table 1.

The cooking times and the corresponding volumes of water for each cooking operation are summarised. There were significant differences ($p<0.05$) in the cooking time when the raw sample of *Mallotus subulatus* was cooked using the different processing methods. The duration for cooking of raw (0% hydration levels) sample ranged from 120 min for boiling at elevated pressure to 433 min for steaming at atmospheric pressure. At hydration level of 10%, there was a slight reduction of 4.57 and 71.34% in the cooking time when the legumes were boiled at normal atmospheric pressure and elevated pressure, respectively. At hydration level of 25% there was also a significant difference ($p<0.05$) in the cooking time of the legumes when subjected to varying hydrothermal processing methods. The percentage reduction of 73.78 for BEP and 15.86 for BAP were recorded for the legume. There was further reduction in the cooking time at 50, 75 and 100% hydration levels, for instance, percentage reduction in cooking times were 78.66, 73.17, 50.91 and 35.36% for BEP, SEP, BAP and SAP respectively at 50% hydration level. The highest percentage reduction of 80.18 was observed at 100% hydration level when the legume was boiled at elevated pressure. As Table 1 showed that, it was observed that it took more time to cook by steaming than by boiling at normal atmospheric pressure. For instance, at 0% hydration level, it took 328 min to cook at normal atmospheric pressure by boiling while cooking of the same sample by steaming took 433 min representing 24.25% increase in the total cooking time.

In comparison with the other two hydrothermal processing methods (BEP and SEP) at varying hydration levels (10, 25, 50, 75 and 100%), BAP resulted in decrease in cooking time. Processing at elevated pressure (BEP) was observed to show better reduction in the cooking time than processing at normal atmospheric pressure. In addition, BEP was observed to induce better reduction in the cooking time than SEP. It is evident from the results that the cooking time of the sample processed at elevated pressure were shorter than those processed at atmospheric pressure. Therefore, it can be inferred that pressure cooking of this legume constitutes an advantage for saving time and energy. Generally, there was decrease in the cooking time as the level of hydration

Table 1: Effect of soaking of Mallotus subulatus at varying hydration levels followed by hydrothermal processing on cooking time

Hydration level (%)	Volume of H_2O used (cm^3)				Cooking time (min)			
	BAP	SAP	BEP	SEP	BAP	SAP	BEP	SEP
0	4700±141.42^{c}	5950±0.00 (21.01)^{d}	2000±70.71 (57.45)^{a}	2380±0.00 (49.36)^{b}	328±2.00^{c}	433±3.00 (24.25)*^{d}	120±2.00 (63.41)^{a}	156±5.00 (52.43)^{b}
10	4100±0.00 (12.77)^{c}	5320±20 (11.65)*^{d}	1800±100 (61.70)^{a}	2150±10 (54.26)^{b}	313±4.24 (4.57)^{d}	293±4.24 (10.67)^{c}	194±2.82 (71.34)^{b}	117±0.71 (64.33)^{a}
25	1800±0.00 (10.00)^{c}	3340±70.71 (28.94)^{d}	1600±21.23 (65.96)^{a}	1920±14.10 (59.15)^{b}	276±0.71 (15.86)^{c}	275±0.00 (16.16)^{c}	86±0.70 (73.78)^{a}	107±1.41 (52.44)^{b}
50	2300±35.36 (51.06)^{c}	2900±0.00 (38.30)^{d}	1530±21.21 (67.45)^{a}	1770±49.49 (62.34)^{b}	161±0.70 (50.91)^{c}	212±2.12 (35.36)^{d}	70±0.00 (78.66)^{a}	88±0.70 (73.17)^{b}
75	2300±0.00 (51.06)^{c}	2800±56.57 (40.43)^{d}	1500±28.28 (68.09)^{a}	1740±56.57 (62.98)^{b}	151±0.71 (53.96)^{c}	199±2.83 (39.33)^{d}	67±1.40 (79.57)^{a}	84±0.71 (74.39)^{b}
100	2150±35.36 (54.26)^{c}	2690±120.21 (42.77)^{d}	1500±28.28 (64.09)^{a}	1700±42.43 (63.83)^{b}	118±1.41 (64.02)^{c}	156±1.41 (52.44)^{d}	65±0.00 (80.18)^{a}	76±0.74 (76.83)^{b}

Values are Means±Standard Deviation (n = 3), means with different letters on the same row are significant ($p<0.05$). Values in parenthesis represent percentage reduction. Values with * represent percentage increase. BAP: Boiling at normal atmospheric pressure, SAP: Steaming at normal atmospheric pressure, BEP: Boiling at elevated pressure, SEP: Steaming at elevated pressure

increased. Similarly, the quantity of water used to achieve cooking decrease with increase in hydration level. Under normal circumstances, most food cooked by boiling at 100°C. This is because water boils at this temperature at normal atmospheric pressure (760 mm/Hg). By increasing the pressure inside a pressure cooker above normal atmospheric pressure, the temperature inside the pressure cooker increases. In a study, the pressure inside a pressure cooker was increased to 15 lbs per square inch above atmospheric pressure. This increase in pressure caused cooking temperature to rise by about 21.5°C. In general, foods cook faster if the temperature of cooking is raised[18,19].

Effects of hydrothermal processing methods on the proximate composition of the legume seeds: Table 2 shows the effects of soaking at varying hydration levels, ranging from 0-100%, followed by hydrothermal processing on the proximate composition of the legume samples. Hydrothermal processing of the legume seeds had significant effects ($p<0.05$) on the proximate composition. The protein content of the raw sample (0% hydration level) was 20.97%. As shown in Table 2, boiling of *Mallotus subulatus*, without soaking (i.e., 0% hydration level), at normal atmospheric pressure (BAP) caused a change of 22.06% reduction in the protein content while steaming at the same pressure induced a reduction of 23.36% in protein content. Hydrothermal processing of *Mallotus subulatus* at elevated pressure by boiling resulted in 10.58% reduction while that of pressure steaming was 11.77%. As presented in Table 2, boiling of the legume at 10% hydration level decreased its protein to 16.37% representing 21.94% reduction which is lower than 19.96% recorded for 75 and 100% hydration levels at normal atmospheric pressure. However, upon boiling at elevated pressure, the protein content of the sample at 10% hydration level was 18.75% representing 10.58% reduction while percentage reduction of 5.39% was recorded at 25% hydration level. With increasing hydration level the percentage reduction in protein content decreased. This was true for all the hydrothermal processing methods. Steaming at normal atmospheric pressure as well as steaming at elevated pressure resulted in percentage reduction of 23.37 and 11.78% protein, respectively at 10% hydration level. The lowest decrease in protein content to 16.07% recorded for the legume sample using steam at normal atmospheric pressure was probably due to the relatively longer cooking times resulting in leaching. In comparison, boiling at elevated pressure of 80±8 kPa appeared to have minimal negative effects on the crude protein content of the legume seeds. The protein content of 18.75% was recorded at hydration level of 0% after boiling at elevated pressure while steaming at normal atmospheric pressure of the same *Mallotus subullatus* at hydration level of 0% reduced the crude protein content to 16.07%. There appeared to be more reduction in the protein content of the legume when it was processed without soaking (i.e., 0% hydration level). This was probably due to the fact that the sample processed without soaking (i.e., 0% hydration level) spent more time during cooking than those that were soaked prior to thermal processing. This percentage reduction due to soaking, however, could be attributed to decrease in cooking times caused by increase in the hydration levels. Soaking before processing predisposes soluble components of protein to leaching[20,21].

The observed decrease in protein content during thermal processing agrees with the earlier finding of Abdullahi *et al.*[22]. In that report, the crude protein content of an unconventional legume, *Albazzia lebbeck* seeds was 38.04%. After boiling for 15, 30 and 60 min the crude protein content of *Albazzia lebbeck* seeds decreased to 36.88, 35.90 and 33.88%, respectively. Also, toasting of *Albazzia lebbeck* for 60, 120 and 180 min reduced the protein content to 31.39, 30.55 and 29.70%, respectively[8]. This was probably due to denaturation caused by the unzipping of the hydrophobic forces leading to partial disruption of the primary structure of protein molecules. Similarly, in another report, the protein content of *Senna occidentalis*, decreased significantly from 19.64% in the raw seeds to 17.60% in the cooked seeds[22].

In general, there appeared to be better retention of protein content for processing at elevated pressure with boiling having comparative advantage over steaming. The BEP caused better retention of protein than steaming. This might be due to the fact that boiling involved soaking during which the legume seeds absorb water and thereby increasing the hydration level. Increasing the hydration level as earlier observed, decreased the cooking time and hence minimize leaching. Unlike boiling, steaming or toasting, fermentation and germination increased the crude protein contents of mung beans and soybeans[20]. Protein increase in germinated and fermented seeds was attributed to protein synthesis induced by enzymes activation during germination and fermentation while the reduction noticed in boiled seeds was attributed to leaching[20,21].

The moisture content of the raw and processed samples were generally low. The moisture content of dried raw sample was 10.11%. At hydration levels of 0, 10, 25 and 50%, the moisture content after processing ranged from 8.02-8.98, 8.01-9.00, 7.98-8.97 and 8.00-8.98%, respectively while the moisture contents in the range of 8.00-8.96% was recorded for both 75 and 100% hydration levels.

Table 2: Effect of varying hydration levels followed by hydrothermal processing on proximate composition

Hydration level (%)	Proximate component (%)	RS	BAP	SAP	BEP	SEP
0	Moisture content	10.11±0.40^{d}	8.98±0.05 (11.17)^{c}	8.40±0.02 (16.91)^{b}	8.02±0.06 (20.67)a	8.05±0.10 (20.37)^{a}
	Ash	4.38±0.21^{e}	2.79±0.03 (36.30)^{b}	2.62±0.00 (40.18)^{a}	3.88±0.10 (11.41)^{d}	3.82±0.13 (12.78)^{c}
	Crude protein	20.97±0.77^{e}	16.35±0.68 (22.06)^{b}	16.07±0.72 (23.36)^{a}	18.75±0.52 (10.58)^{d}	18.50±0.32 (11.77)^{c}
	Ether extract	0.97±0.02^{d}	0.92±0.01 (5.15)^{c}	0.87±0.00 (10.30)^{a}	0.90±0.01 (7.21)^{b}	0.90±0.01 (7.21)^{b}
	Crude fibre	9.68±0.45^{e}	9.21±0.07 (14.85)^{d}	8.75±0.06 (9.60)^{a}	9.34±0.47 (3.51)^{b}	9.25±0.22 (4.44)^{d}
	Carbohydrate	53.89±.1.22^{a}	61.75±0.41 (12.72)^{d}	63.29±0.97 (14.85)^{e}	59.11±1.04 (8.83)^{b}	59.48±0.80 (9.39)^{c}
	Total dry matter	89.89±1.97^{a}	91.02±1.20 (1.24)^{b}	91.60±1.24 (1.86)^{c}	91.98±1.03 (2.27)^{c}	97.95±1.28 (8.22)^{d}
10	Moisture content	10.11±0.40^{d}	9.00±0.04 (10.98)^{c}	8.38±0.04 (17.11)^{b}	8.01±0.06 (20.87)^{a}	8.01±0.10 (20.77)^{a}
	Ash	4.38±0.21^{c}	2.79±0.05 (36.30)^{a}	2.64±0.00 (39.73)^{a}	3.95b±0.10 (9.82)^{c}	3.82±0.12 (12.79)^{b}
	Crude protein	20.97±0.77^{e}	16.37±0.80 (21.94)^{b}	16.07±0.03 (23.37)^{a}	18.75±0.52 (10.58)^{d}	18.50±0.21 (11.78)^{c}
	Ether extract	0.97±0.02^{d}	0.92±0.01 (5.15)^{c}	0.87±0.00 (10.31)^{a}	0.90±0.01 (7.21)^{b}	0.90±0.01 (7.21)^{b}
	Crude fibre	9.68±0.45^{e}	9.21±0.08 (4.86)^{b}	8.75±0.11 (9.61)^{a}	9.35±0.46 (3.41)^{d}	9.25±0.22 (4.44)^{c}
	Carbohydrate	53.89±1.22^{a}	61.71±0.42 (12.67)^{d}	63.29±0.97 (14.85)^{e}	59.04±1.11 (8.72)^{b}	59.52±1.01 (9.46)^{c}
	Total dry matter	89.89±1.97^{a}	91.00±0.49 (1.22)^{b}	91.62±1.32 (1.89)c	91.99±1.22 (2.28)^{d}	91.99±1.31 (2.28)^{d}
25	Moisture content	10.11±0.40^{e}	8.97±0.11 (11.28)^{d}	8.39±0.05 (17.01)^{c}	7.98±0.05 (21.07)^{a}	8.04±0.08 (20.48)^{b}
	Ash	4.38±0.21^{e}	3.25±0.05 (25.80)^{b}	3.10±0.10 (29.22)^{a}	4.01±0.14 (8.45)^{d}	3.90±0.10 (10.96)^{c}
	Crude protein	20.97±0.77^{e}	17.08±0.75 (18.55)^{b}	16.72±0.31 (20.27)^{a}	19.84±0.47 (5.39)^{d}	19.65±0.50 (6.30)^{c}
	Ether extract	0.97±0.02^{c}	0.92±0.02 (5.16)^{b}	0.87±0.01 (10.31)^{a}	0.90±0.01 (7.22)^{b}	0.90±0.00 (7.22)^{b}
	Crude fibre	9.68±0.45^{e}	9.22±0.07 (4.75)^{b}	8.75±0.04 (4.61)^{a}	9.36±0.50 (3.31)^{d}	9.25±0±.20 (4.44)^{c}
	Carbohydrate	53.89±.1.22^{a}	60.56±0.09 (11.01)^{d}	62.17±0.68 (13.32)^{e}	57.91±1.10 (6.44)^{b}	58.26±1.00 (7.50)^{c}
	Total dry matter	89.89±1.97^{a}	91.03±1.02 (4.25)^{b}	91.61±1.41 (4.88)^{c}	92.02±1.53 (4.39)^{e}	91.96±0.99 (2.25)^{d}
50	Moisture content	10.11±0.40^{e}	8.98±0.05 (11.18)^{d}	8.40±0.03 (16.91)^{c}	8.00±0.02 (20.07)^{a}	8.12±0.09 (19.68)^{b}
	Ash	4.38±0.21^{e}	3.78±0.10 (13.70)^{b}	3.63±0.20 (17.20)^{a}	4.21±0.11 (3.88)^{d}	4.06±0.07 (7.31)^{c}
	Crude protein	20.97±0.77^{e}	17.38±0.55 (17.12)^{b}	17.08±0.05 (18.55)^{a}	19.86±0.69 (5.29)^{d}	19.69±0.34 (6.10)^{c}
	Ether extract	0.97±0.02^{d}	0.93±0.04 (4.12) ^{b}	0.92±0.01 (5.16)a	0.92±0.00 (5.16)^{a}	0.94±0.01 (3.09)^{c}
	Crude fibre	9.68±0.45^{c}	9.47±0.10 (2.17)^{b}	19.35±0.00 (3.41)^{d}	9.47±0.51 (2.17)^{b}	9.30±0.15 (3.93)^{a}
	Carbohydrate	53.89±.1.22^{b}	59.46±0.51(9.37)^{e}	50.62±1.00 (6.68)^{a}	57.54±1.04 (6.34)^{c}	57.89±0.81 (6.91)^{d}
	Total dry matter	89.89±1.97^{a}	91.02±2.00 (1.24)^{b}	91.60±0.89 (1.87)^{c}	92.00±1.67 (2.29)^{e}	91.88±1.04 (2.17)^{d}
75	Moisture content	10.11±0.40^{e}	8.96±0.12 (11.38)^{d}	8.40±0.02 (16.91)^{c}	8.00±0.10 (20.07)^{a}	8.11±0.05 (19.8)^{b}
	Ash	4.38±0.21^{e}	4.01±0.06 (8.45)^{b}	3.85±0.13 (22.83)^{a}	4.21±0.11 (3.88)^{d}	4.08±0.10 (6.85)^{c}
	Crude protein	20.97±0.77^{e}	19.96±0.74 (4.82)^{c}	19.66±0.15 (6.25)^{a}	20.00±0.53 (4.63)^{d}	19.77±0.26 (0.72)^{b}
	Ether extract	0.97±0.02^{c}	0.95±0.05 (2.06)^{b}	0.92±0-.00 (5.16)^{a}	0.95±0.01 (2.06)^{b}	0.95±0.00 (2.06)^{b}
	Crude fibre	9.68±0.45^{e}	9.55±0.05 (1.34)^{c}	9.38±0.04 (3.10)^{a}	9.57±0.60 (1.14)^{d}	9.42±0.21 (2.69)^{b}
	Carbohydrate	53.89±1.22^{a}	56.57±0.53 (4.74)^{b}	57.79±0.26(6.75^{e}	57.27±0.99 (5.90)^{c}	57.67±0.54 (6.56)^{d}
	Total dry matter	89.89±1.97^{a}	91.04±2.02 (1.26)^{b}	91.60±0.94(1.87^{c}	92.00±1.03 (2.29)^{e}	91.89±1.02 (2.18)^{d}
100	Moisture content	10.11±0.40^{e}	8.96±0.12 (1.37)^{d}	8.40±0.02(16.91)^{c}	8.00±0.10 (20.87)^{a}	8.11±0.05 (19.78)^{b}
	Ash	4.38±0.21^{e}	4.01±0.06 (8.45)^{b}	3.85±0.13(12.10)^{a}	4.21±0.11 (3.88)^{d}	4.08±0.10 (6.85)^{c}
	Crude protein	20.97±0.77^{e}	19.96±0.74 (4.82)^{c}	19.66±0.15(6.25)^{a}	20.00±0.53 (4.63)^{d}	19.77±0.26 (5.72)^{b}
	Ether extract	0.97±0.02^{c}	0.95±0.05 (2.06)^{b}	0.92±0-.00(5.15)^{a}	0.95±0.01 (2.06)^{b}	0.95±0.00 (2.06)^{b}
	Crude fibre	9.68±0.45^{e}	9.55±0.05 (1.34)^{c}	9.38±0.04(3.10)^{a}	9.57±0.60 (1.14)^{d}	9.42±0.21 (2.69)^{b}
	Carbohydrate	53.89±1.22^{a}	56.57±0.53 (4.73)^{b}	57.79±0.26(6.72^{e}	57.27±0.99 (5.90)^{c}	57.67±0.54 (6.55)^{d}
	Total dry matter	89.89±1.97^{a}	91.04±2.02 (1.26)^{b}	91.60±0.94(1.86)^{c}	92.00±1.03 (2.29)^{e}	91.89±1.02 (2.17)^{d}

Values are Means±Standard deviation (n=3) on dry basis, means with different letters on the same row are significant ($p<0.05$). Values in parenthesis represent percentage change in concentration after processing.
RS: Raw dried sample, BAP: Boiling at normal atmospheric pressure, SAP: Steaming at normal atmospheric pressure, BEP: Boiling at elevated pressure, SEP: Steaming at elevated pressure

Hydrothermal processing did not induce remarkable change in the oil content of the legumes. Generally, the oil content of the legume seed samples before and after thermal processing were low and hence they do not qualify as oil seeds.

All the hydrothermal processing methods had significant effect ($p<0.05$) on the total ash content of the legume samples. The total ash content of the raw sample was 4.38%. After hydrothermal processing the percentage ash contents were reduced to 2.79, 2.62, 3.88 and 3.82% for BAP, SAP, BEP and SEP, respectively at 0% hydration level. At varying hydration levels, the legume exhibited varying degrees of percentage reduction in the ash content. At the hydration level of 50%, for instance, the lowest percentage reduction of 5.29% was recorded after boiling at elevated pressure. This was followed by reduction of 6.10% when the legume was processed by steaming at elevated pressure. For the legume studied, there was better retention of total ash at all hydration levels with processing by boiling at elevated pressure (BAP). This might be due to the fact that pressure resulted in the lowest cooking time for the legumes. Generally, there was reduction in the concentration of total ash, with prolonged heating. This might be due to leaching. This is in agreement with an earlier report on another legume *Vigna unguiculata* in which it was reported that the total ash content decreased after boiling[23].

Hydrothermal processing methods induced significant reduction ($p<0.05$) in the crude fibre content of the legumes at varying hydration levels. Without soaking (i.e., 0% hydration level) the raw sample of *Mallotus subulatus* with crude fibre content of 9.68% decreased to 9.21 and 8.75% after processing by boiling and steaming at normal atmospheric pressure, respectively while boiling and steaming at elevated pressure reduced the fibre level to 9.34 and 9.25%, respectively. Hydration of the legume samples to 10% followed by hydrothermal processing also changed the fibre content of the legumes significantly ($p<0.05$). In a study, the crude fibre content of *Senna occidentalis* seeds which was 2.60% reduced to 1.84% after boiling while the raw seeds of an unconventional legume, *Albizzia lebbeck,* with a fibre content of 11.63% had a reduction to the level of 8.78% after boiling for 60 min[8]. Fagbemi[21] reported a similar observation in another study in which the crude fibre content of raw *Senna occidentalis* containing 2.60% crude fibre decreased to 2.49% after boiling.

Mineral elements composition as affected by the different processing conditions: Mineral elements composition and the changes in the mineral elements composition of the legumes at varying hydration levels ranging from 10 -100%, followed by different hydrothermal processing are presented in Table 3. The specific effects of processing on mineral element contents of legumes depend on the methods of processing. Hydrothermal processing methods significantly ($p<0.05$) affected the concentration of the mineral elements in the legume studied.

Although, there was seepage of the mineral elements during hydrothermal processing, the concentration of the minerals were not degraded beyond normal requirements necessary to meet physiological/nutritional needs. This was partly due to the fact that the cooking water was dried alongside with the legume during processing. Losses of mineral in the cooking water drained from cooked legume have been reported[23]. It is therefore important to state that the traditional practice of throwing away cooking water in some localities should be discouraged for the maximum benefit of the mineral elements in the legume.

In general, samples cooked at higher hydration levels (Table 3), appeared to have better retention of mineral elements. This was probably due to the fact that samples with higher hydration levels required less time for cooking. Moreover, the degree of cell wall damage can be assumed to affect the degree of leaching of mineral elements from the legume seeds during hydrothermal processing. This degree of cell wall damage is time dependent during hydrothermal processing thereby making the samples cooked at relatively shorter time as in the case of boiling at elevated pressure, have a better retention of nutritionally important nutrients.

Concentration of antinutritional components in the legume as influenced by soaking: The results of soaking on the level of antinutritional components in the legume are presented in Table 4. At various hydration levels, the percentage reduction of the antinutritional factors varied. Changes were observed in the concentration of phytic acid in the legume after soaking at varying hydration levels. The percentage reduction in the phytic acid for the sample ranged from 4.71-12.06%. Generally, these percentage reductions in the concentration of phytic acid after soaking were comparable to but relatively lower than earlier results on another legume, *Mucuna flagellipes*. Udensi *et al.*[24] reported 27.9% reduction in phytic acid content of *Mucuna flagellipes* after soaking for 6 h and 36.0% reduction after soaking for 24 h at ambient temperature. Similarly, 9.7% reduction in the content of phytic acid was observed for *Sesbania rastrata* after soaking while 5.0% reduction was observed for *Vigna radiata*[25]. On the contrary, soaking did not alter the concentration of phytic acid in another specie of legume *Sesbania aculenta*[25]. In a study, the

Table 3: Changes in the mineral elements composition of Mallotus subulatus at varying hydration levels followed by hydrothermal processing

Hydration level (%)	Mineral elements (mg/100 g)	RS	BAP	SAP	BEP	SEP
0	Calcium	128.81±1.02^{e}	101.10±0.4721.52)^{b}	96.67±1.03 (25.50)^{a}	110.40±0.30 (14.30)^{d}	108.97±0.80 (15.4)^{c}
	Zinc	20.57±0.31^{e}	15.07±0.06 (6.74)^{b}	13.80±.52 (32.91)^{a}	16.49±0.03 (19.83)^{d}	16.05±0.25 (21.97)^{c}
	Sodium	42.34±0.05^{e}	31.22±0.03 (26.26)^{b}	27.87±0.81(34.18)^{a}	33.64±0.05 (20.55)^{d}	33.24±0.10 (21.49)^{c}
	Iron	5.52±0.02^{e}	3.90±0.03 (29.35)^{b}	3.89±0.03 (29.53)^{a}	4.50±0.01 (18.48)^{d}	4.26±0.04 (22.83)^{c}
	Magnesium	140.53±1.02^{e}	72.70±0.56 (48.27)^{b}	71.97±1.35 (48.79)^{a}	102.52±1.02 (27.05)^{d}	101.08±0.85 (28.07)^{c}
	Phosphorus	240.24±1.10^{e}	126.80±0.41 (47.22)^{a}	127.35±0.61 (46.99)^{b}	158.51±1.00 (34.02)^{d}	158.00±1.08 (34.23)^{c}
	Potassium	146 .51±0.81^{e}	101.88±0.67 (30.46)^{b}	95.40±0.90 (34.88)^{a}	129.98±0.67 (11.28)^{d}	128.77±0.75 (12.11)^{c}
10	Calcium	128.81±1.02^{e}	101.10±0.32 (21.52)^{b}	99.11±1.00 (23.06)^{a}	110.49±0.29 (14.23)^{d}	108.95±1.00 (15.42)^{c}
	Zinc	20.57±0.31^{e}	15.07±0.03 (26.74)^{b}	13.80±0.50 (32.91)^{a}	16.57±0.04 (19.45)^{d}	16.49±0.43 (19.83)^{c}
	Sodium	42.34±0.05^{e}	31.24±0.07 (25.98)^{b}	27.89±0.45 (34.13)^{a}	33.84±0.05 (20.08)^{d}	33.78±0.10 (20.22)^{c}
	Iron	5.52±0.02^{e}	3.94±0.03 (28.62)^{b}	3.92±0.02 (28.99)^{a}	4.52±0.01 (18.12)^{d}	4.26±0.05 (22.83)^{c}
	Magnessium	140.53±1.02^{e}	72.75±0.38 (48.23)^{b}	71.9±0.98 (48.84)^{a}	102.68±1.11 (26.93)^{c}	108.08±0.73 (22.58)^{d}
	Phosphorus	240.24±1.10^{e}	127.77±0.41 (46.82)^{b}	127.38±0.28 (46.98)	160.45±0.62 (33.21)^{d}	148.29±0.88 (38.27)^{c}
	Potassium	146 .51±0.81^{e}	101.88±1.22 (30.46)^{b}	95.41±1.23 (34.88)^{a}	130.76±0.71 (10.75)^{d}	128.24±0.70 (12.47)^{c}
25	Calcium	128.81±1.02^{e}	102.52±0.28 (20.41)^{b}	101.22±2.01 (21.42)^{a}	112.04±0.29 (13.02)^{d}	111.66±0.79 (13.32)^{c}
	Zinc	20.57±0.31^{e}	15.42±0.24 (25.04)^{b}	14.92±0.61 (27.47)^{a}	17.02±0.10 (17.26)^{d}	16.97±0.32 (17.50)^{c}
	Sodium	42.34±0.05^{e}	31.00±0.10 (26.78)^{b}	28.44±0.32 (32.83)^{a}	33.60±0.04 (20.64)^{d}	33.78±0.06 (20.21)^{c}
	Iron	5.52±0.02^{e}	3.94±0.02 (28.62)^{b}	3.92±0.02 (28.99)a	4.54±0.03 (17.75)^{d}	4.39±0.03 (20.47)^{c}
	Magnessium	140.53±1.02^{e}	84.02±0.41 (40.21)^{b}	72.38±1.11 (48.49)^{a}	113.05±1.01 (19.55)^{d}	109.42±1.23 (22.14)^{c}
	Phosphorus	240.24±1.10^{e}	132.69±0.36 (44.77)^{b}	128.88±0.18 (46.35)^{a}	165.06±0.60 (31.29)^{d}	161.01±1.02 (32.98)^{c}
	Potassium	146 .51±0.81^{e}	103.78±1.34 (29.16)^{b}	101.17±0.87 (30.95)^{a}	134.82±1.23 (7.98)^{d}	130.91±0.81 (10.65)^{c}
50	Calcium	400.36±1.34^{e}	105.45±0.53 (18.14)^{b}	102.95±0.98 (20.08)^{a}	113.91±0.41 (11.57)^{d}	113.31±0.83 (12.04)^{c}
	Zinc	14.73±0.50^{e}	16.01±0.23 (22.17)^{b}	15.59±0.92 (24.21)^{a}	17.60±0.12 (14.44)^{d}	17.20±0.40 (16.38)^{c}
	Sodium	47.22±1.01^{e}	34.00±0.13 (19.70)^{b}	32.12±0.71 (24.14)^{a}	36.59±0.11 (13.58)^{d}	36 .55±0.08 (13.68)^{c}
	Iron	4.26±0.03 ^{e}	4.40±0.06 (20.29)^{b}	4.08±0.04 (26.09)^{a}	4.49±0.02 (18.66)^{d}	4.46±0.41 (19.20)^{c}
	Magnessium	120.77±0.46^{e}	85.50±0.50 (39.16)^{b}	82.53±1.36 (41.27)^{a}	115.53±1.02 (17.79)^{c}	118.30±1.41 (15.82)^{d}
	Phosphorus	395 .67±2.07^{e}	150.00±0.60 (37.56)^{b}	147.25±0.30 (38.71)^{a}	184.01±0.54 (23.41)^{d}	182.10±1.01 (24.20)^{c}
	Potassium	350.78±1.76^{e}	106.90±0.16 (27.04)^{b}	105.41±1.31 (28.05)^{a}	136.50±0.51 (16.83)^{d}	136.20±0.00 (17.04)^{c}
75	Calcium	128.81±1.02^{d}	108.97±.51 (15.41)^{b}	105.89 1.01 (17.80)^{a}	119.24±0.32 (7.57)^{c}	119.24±0.83 (7.57)^{c}
	Zinc	20.57±0.31^{e}	16.01±0.2322.16)^{b}	15.59±1.01(24.2)^{a}	17.61±0.03 (14.38)^{d}	17.20±0.37 (16.38)^{c}
	Sodium	42.34±0.05^{e}	34.00±0.07 (19.69)^{b}	32.80±0.64 (22.53)^{a}	36.59±0.12 (13.58)^{d}	36.55±0.12 (13.67)^{c}
	Iron	5.52±0.02^{e}	4.50±0.01 (18.47)^{c}	4.08±0.02 (26.08)^{a}	5.10±0.10 (7.60)^{d}	4.47±0.03 (19.02)^{b}
	Magnessium	140.53±1.02^{e}	85.54±0.44 (39.13^{b}	82.65±1.10 (41.18)a	115.55±1.34 (17.81)^{c}	118.30±0.95 (15.81)^{d}
	Phosphorus	240.24±1.10^{e}	150.03±0.08 (37.54^{b}	147.25±0.28 (38.70)^{a}	184.27±1.01(23.29)^{d}	182.78±0.92 (23.91)^{c}
	Potassium	146 .51±0.81^{e}	106.90±1.02 (7.03) ^{b}	105.52±1.80 (27.97)^{a}	136.51±0.50 (6.82)^{d}	136.31±0.53 (6.96)^{c}
100	Calcium	128.81±1.02^{d}	108.50±0.47 (15.77)^{b}	105.86±1.10 (17.82)^{a}	119.51±0.33 (7.22)^{c}	119.15±1.12 (7.50)^{c}
	Zinc	20.57±0.31^{e}	17.93±0.14 (12.83)^{b}	15.00±1.00 (27.08)^{a}	19.43±0.15 (5.54)^{d}	19.40±0.35 (5.69)^{c}
	Sodium	42.34±0.05^{d}	35.69±.12 (15.71)^{b}	33.61±0.56 (20.62)^{a}	38.29±0.03 (9.57)^{c}	38.29±0.10 (9.57)^{c}
	Iron	5.52±0.02^{e}	4.53±0.03 (17.93)^{b}	4.38±0.04 (20.65)^{a}	5.23±0.10 (5.25)^{d}	5.00±0.03 (9.42)^{c}
	Magnessium	140.53±1.02^{e}	87.13±0.62 (37.99)^{b}	84.38±0.61(39.96)^{a}	118.31±0.81 (15.81)^{d}	118.30±0.81 (15.82)^{c}
	Phosphorus	240.24±1.10^{e}	151.35±0.50 (37.00)^{b}	149.47±0.34 (37.78)^{a}	186.84±1.02 (22.23)^{d}	184.03±0.85 (23.39)^{c}
	Potassium	146 .51±0.81^{e}	106 .95±0.72 (27.00)^{b}	105.52±1.35 (27.98)^{a}	136.51±0.40 (6.83)^{d}	136.50±0.50 (6.83)^{c}

Values are Means±Standard deviation (n=3) on dry basis, means with different letters on the same row are significant ($p<0.05$). Values in parenthesis represent percentage change in concentration after processing.
RS: Raw dried sample, BAP: Boiling at normal atmospheric pressure, SAP: Steaming at normal atmospheric pressure, BEP: Boiling at elevated pressure, SEP: Steaming at elevated pressure

maximum reduction of 37% in the level of phytic acid occurred when the seeds of *B. purpurea* were soaked in distilled water for 6 h at 24°C[26]. The percentage reduction in phytic acid content increased with increasing soaking time up to 6 h. The loss in the phytic acid content was mainly due to leaching and is particularly favoured when the compound posseses low molecular weight and ionic character[27]. The removal of phytic acid during soaking has also been attributed to degradation of the phytate molecule followed by diffusion of the phytase enzyme which is activated in the seeds[28].

Changes in the concentration of saponin before and after soaking at varying hydration levels were recorded in Table 4. In the saponin content the sample reduced after soaking. There was progressive decrease in the saponin content as the hydration levels increased. The saponin content of dried raw *Mallotus subulatus* was 10.21 mg g^{-1}. This sample exhibited 0.67% reduction at 10% hydration level and 3.23% reduction at 100% hydration level.

Trypsin Inhibitor (TI) was reduced at varying levels of hydration. The percentage reduction increased with increase in hydration level. At 10% hydration level, the percentage reduction was 9.51% and at 100% hydration level, it was 27.00%.

The percentage reductions in tannin content of the samples studied were similar but comparatively lower than those of a previous report on *Mucuna flagellipes* which ranged from 58.4% at 6 h of soaking to 74.9% at 24 h of soaking[24]. The lower values of reductions recorded might be due to differences in species. Reduction in tannin content of some beans by soaking in different solutions has also been reported[26]. Pinto beans with high tannin content exhibited the highest reduction in tannin content after soaking whereas cranberry beans with low tannin content lost less tannin during soaking. Reduction in the tannin content might be due to leaching out of the polyphenols into the soaking water[29]. Tannins are polyphenols and polyphenolic compounds are mostly water soluble in nature and mostly located in the seed coat. It can be inferred that soaking as a pre-processing method can be used to reduce the level of some water soluble/leachable antinutrients.

Antinutritional components in the processed legume samples: The effects of hydrothermal processing methods on the level of antinutritional components in *Mallotus subulatus* are summarised in Table 5. All the hydrothermal processing methods had reduction effects on the antinutritional factors investigated. The percentage reduction was dependent on the methods of processing and duration of heating. The percentage reduction for each of the antinutritional

Table 4: Concentration of antinutrtional components (mg g^{-1}) in Mallotus subulatus after soaking at varying hydration levels

	Antinutrtional component					
Hydration level (%)	0	10	25	50	75	100
Phytic acid	71.34±0.72^{e}	67.98±0.53 (4.71)^{d}	65.60±0.25 (8.05)^{c}	63.57±0.44 (10.89)^{b}	62.75±0.60 (12.04)^{a}	62.73±0.45 (12.06)^{a}
Saponin	10.21±0. 43^{d}	10.14±0.28 (0.69)^{c}	10.00±0.17 (2.01)^{b}	9.89±0.30 (3.13)^{a}	9.88±0.12 (3.23)^{a}	9.88±0.98 (3.23)^{a}
Trypsin inhibitor	34.37±0.32^{f}	31.10±0.22 (9.51)^{e}	28.29±0.18 (17.69)^{d}	26.70±0.24 (22.32)^{c}	25.48±0.30 (25.87)^{b}	25.09±0.06 (27.00)^{a}
Tanin	28.10±1.22^{f}	27.03±0.10 (3.81)^{e}	26.07±0.14 (7.22)^{d}	25.32±0.21 (9.89)^{c}	24.28±0.07 (13.59)^{b}	24.02±0.11 (14.52)^{a}

Values are Mean±Standard deviation (n = 3), means with different letters in the same row are significantly different ($p<0.05$). Values in parenthesis represent the percentage loss

Table 5: Antinutritional components of Mallotus subulatus as influenced by hydrothermal processing methods (mg g^{-1})

	Processing conditions				
Antinutrtional component	RS	BAP	SAP	BEP	SEP
Phytic acid	71.34±0.72^{d}	29.32±0.22 (58.90)^{a}	32.63±0.51 (54.26)^{c}	31.03±0.42 (56.50)^{b}	31.40±0.28 (55.99)^{b}
Saponin	10.21±0.43^{d}	0.97±0.07 (90.50)^{a}	1.32±0.20 (87.07)^{b}	0.97±0.02 (90.50)^{a}	1.37±0.12 (86.58)^{c}
Trypsin inhibitor	34.37±0.32^{b}	0.00±0.00 (100.00)^{a}	0.00±0.00 (100.00)^{a}	0.00±0.00 (100.00)^{a}	0.00±0.00 (100.00)^{a}
Tanin	28.10±0.22^{e}	6.85±0.32 (75.62)^{a}	7.84±0.40 (72.10)^{c}	7.57±0.05 (73.06)^{b}	8.15±0.13 (70.99)^{d}

Values above are Means±Standard deviation (n = 3), means with different letters in the same row are significant ($p<0.05$). Values in parenthesis represent percentage decrease, RS: Raw dried sample, BAP: Boiling at normal Atmospheric Pressure, SAP: Steaming at normal atmospheric pressure, BEP: Boiling at elevated pressure, SEP: Steaming at elevated pressure

components after hydrothermal processing are also presented in parenthesis in Table 5. Boiling of the legume at normal atmospheric pressure reduced its phytic acid contents by 58.90% while steaming reduced it by 54.26%. These results are comparable to the observation of Xu and Chang[30], who reported reduction ranges of 21.6-21.9% of phytic acid when lentil was cooked using different cooking treatments. Also, the results were comparable but higher than the value obtained by Wang *et al*.[31], who found out that cooking caused 15.9% reduction in phytate level. Seeds of *B. purpurea* lost 29% of phytic acid during cooking[26].

Traditionally, phytic acid is regarded as one of the antinutritional factors in legumes. The presence of these antinutritional factors in legumes impairs the digestion of proteins, decreases the bioavailabilbity of mineral elements such as Ca, Fe and Zn and therefore reduces the nutritional values of legumes[21,27]. However, it has been reported in recent time that small quantity of phytic acid is of good benefit as antioxidants[5,30]. Reduction in glycemic index as well as lower plasma cholesterol and triglyceride levels have been observed with endogenous phytate consumed in foods. Hence, phytate may play an important role in controlling hypercholesteroleamia and artherosclerosis[5,6]. Moreover, it has been demonstrated that phytic acid has anticancer properties in the mammary gland and colon in rodent models[32]. Also, phytic acid releases inositol during digestion. Although inositol is not an essential nutrient, it might reduce depression. Studies also show that phytic acid may reduce inflammation[33,34]. Therefore, reduction of phytic acid is expected to enhance the bioavailability of proteins and mineral elements in legumes and at the same time the retained small quantity of phytic acid in the cooked legumes may still be of good health benefits.

Saponin was present at varying concentration in the legume studied. All the hydrothermal processing methods significantly reduced the level of saponin in the legume. After hydrothermal processing, the range of reduction of saponin in *Mallotus subulatus* was 86.58-90.50%. As in the case of phytic acid, boiling appeared to induce higher reduction percentage than steaming. These results agree with earlier findings of Abdullahi *et al*.[8] on *Albizzia lebbeck* who reported reduction percentages of 12.54 and 50.00 after boiling for 30 and 60 min, respectively. Saponins are chelating agents, their presence at high concentration limits the availability of essential nutrients. This could be due to the interactions with the lumen resulting in the formation of non-absorbable complexes or to an interaction with the brush membranes of the mucosal cells, leading to an impairment of active nutrient absorption[35]. However, interractions between saponins and biological membranes are not entirely detrimental. It has been proposed that the sensory properties of some saponins may be due to specific interractions with receptor membranes[35].

After hydrothermal processing, a percentage loss of 100% Trypsin Inhibitor Activity (TIA) was observed for the legume. This implies that various hydrothermal processing methods resulted in complete elimination of trypsin inhibitor. These results agree with the earlier findings on *Luffa aegyptiaca* in which domestic processing eliminated trypsin inhibitor[36]. After boiling of *Prosopis africana* seeds for 4 h, complete (i.e., 100%) destruction of trypsin inhibitor was also reported[37].

Pressure processing, both boiling and steaming resulted in relatively lower losses of tannin than atmospheric processing of boiling and steaming. Pressure processing caused relatively lower loss because of shorter processing times. These results agree with the study of Xu and Chang[30] on green pea, yellow pea and chick pea. Percentage reductions of 65.8, 65.8, 74.3 and 74.3% were recorded after regular boiling of *Mucuna flagellipes* for 30, 45, 60 and 90 min respectively[24]. In general, hydrothermal processing methods caused marked reduction in the tannin content of the legume. Tanins are water-soluble phenolic compounds[25]. Tannin reduction during hydrothermal processing of legumes may be attributed to leaching out of the phenol into the cooking water.

CONCLUSION

Hydrothermal processing methods have significant effects on the chemical compositions of the legume studied. Although hydrothermal processing methods resulted in varying degrees of losses of nutrients through leaching, the quantity of nutrients remaining after processing are of nutritional importance to meet physiological/nutritional needs. Generally, the extent of reduction of nutrients in the legume was dependent on the hydration levels, hydrothermal processing methods employed and duration of application of the processing methods. In general, samples cooked at higher hydration levels appeared to have better retention of nutrients. The study will encourage adaptation of this lesser known legume, strengthening dietary diversity and healthy eating habits thereby making a significant contribution to solving the problem of PEM and the wider problems of food and nutrition insecurity in developing countries. This will also prevent imminent extinction of this lesser known hard-to-cook food crop.

SIGNIFICANCE STATEMENTS

- Effects of hydrothermal methods on the components of *M. subullatus* were examined
- Hydrothermal processing had significant effects on nutrients and antinutrients
- Increase in hydration level before hydrothermal processing reduced cooking time
- Boiling at elevated pressure conserves nutrients of this hard-to-cook legume
- The study will encourage adaptation of this underutilized legume and strengthen dietary diversity

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