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Effects of Different Processing Methods on the Antinutritional Factors Present in Mungbean (*Vigna radiata* L.)

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Abstract: The main aim of this study was to determine the effects of different processing methods on the antinutritional factors of mungbean (*Vigna radiata* L.) of the Pusa Baisakhi variety. The values obtained were as follows: tannin 477 mg/100 g, oxalate 227 mg/100 g, phytate 627 mg/100 g, total phenolic content 772 mg/100 g, and saponin 2618 mg/100 g in raw mungbean, on a dry basis. The maximum reduction in tannin (63%) was observed when the mungbean was processed by the soaking and dehulling processes. The reduction achieved by soaking for 12 h and germination for 36 h was the most effective method in reducing the phytate content of mungbean (39%). The maximum reduction in saponin (22%) and oxalate (71%) was observed by autoclaving the soaked seeds. In comparison to other methods, roasting was the least effective method to reduce tannin, phytate, and oxalate. Autoclaving of the soaked seeds was the most effective method for reducing the antinutrients of mungbean among the cooking treatments. The processing methods such as soaking, dehulling, germination, roasting, raw open cooking, raw autoclaving, soaked open cooking, and autoclaving of soaked seeds significantly reduced the antinutrient contents of mungbean ($p < 0.05$). However, the effects of the treatments combined were more effective than those of the single process.

Keywords: mungbean; antinutritional factors; processing methods; germination; cooking

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1. Introduction

Legumes are crops that are included in flowering plants and produce seeds in pods that are often refined for food and feed [1]. They are a significant source of dietary proteins and serve as a major source of protein in the diets of the lower income groups of underdeveloped and developing countries, where animal protein is hardly affordable [2]. Mungbean (*Vigna radiata* L.), also known as green gram, is consumed worldwide, primarily in Asian countries, and has a long history of use as a traditional medicine [3]. Mungbean production is mainly (90%) situated in Asia [4].

The highest concentrations of antinutrients are found in the grains, beans, legumes, and nuts. The most common antinutrients available in plants are oxalates, tannins, phytates, lectins, and saponins [5]. Although legumes are the most common and the least expensive sources of protein, their utilization is largely limited because of the presence of antinutritional compounds, including trypsin inhibitors, alpha-amylase inhibitors, lectins, tannins, phytic acids, saponins, oxalates, chymotrypsin inhibitors, flatulence factors, hemagglutinin, cyanogenic compounds, and allergens. These compounds reduce the nutritive value of beans as they reduce the digestibility of carbohydrates and proteins, causing pathological alterations in the liver and gut, thus affecting metabolism and inhibiting the enzymes and binding nutrients [6]. Different processing techniques are required to inactivate or remove

antinutritional factors, thereby enhancing the nutritional quality of legumes. Mungbean can be processed by soaking, boiling, cooking, autoclaving, dehulling, and germination, which significantly reduces the antinutrients [1].

In Nepal, mungbean is considered beneficial for health and can be consumed during illness [4]. The mungbean is nutritious and consumed worldwide. It has received recognition as a great source of vitamins, proteins, minerals, dietary fiber, and a notable amount of polysaccharides, peptides, and bioactive compounds such as polyphenols, and has become popular in promoting good health [3]. It has been reported that mungbean assists in moisturizing the skin and regulating gastrointestinal distress. High levels of oligosaccharides, proteins, amino acids, and polyphenols in mungbean could contribute to the anti-melanogenesis, antioxidant, antimicrobial, anti-hypertensive, anti-inflammatory, immunomodulatory, and antitumor activities of this food and regulate lipid metabolism [7]. Cereals are high in sulfur-containing amino acids but low in lysine. Combining mungbean with grains has been suggested as a way to greatly improve the protein quality. A 3:4 ratio of mungbean protein to rice protein was proposed for the highest chemical score of amino acid. The diet including a rice–mungbean combination nearly met the protein requirements in babies, and the protein digestibility was 84.4% in comparison to that of the diet including a rice–meat combination [8].

To lower the antinutrients, different processing methods, and the comparative effectiveness of these methods, are still a subject matter of study. Auer et al. [9] assessed the digestibility and estimated bioavailability/bioaccessibility of plant-based proteins and minerals from various beans and its ingredients. While considering the antinutrients and their influence on the bioavailability of nutrients, the study did not consider the effect of the processing methods on the bioavailability of nutrients. In a study by Ifeanacho and Ezecheta [10], different domestic processing techniques, such as dehulling and shade drying, dehulling and sun drying, fermentation, and sprouting were used. It was concluded that flour from fermented mungbean can be used to prepare nutritious products. The processing methods could help to reduce the health risks associated with the consumption of mungbean as they lower the antinutrients present in mungbean. As a result, attempts to improve the nutritional characteristics of mungbean by the reduction in antinutritional factors are increasing. Thus, this study determined the antinutrient content in mungbean and the effects of various processing methods to reduce these antinutrients. The results of this study might help in the establishment of an effective processing method for the use of mungbean at household and industrial levels.

2. Materials and Methods

2.1. Materials

Mungbean of the Pusa Baisakhi variety was collected from Saptari district (elevation ranging from 61 to 610 m above sea level), Nepal, in March, 2021. The collected samples were brought to Dharan for this study. The sample was stored in a zipper bag after collection, during transportation to the laboratory. All chemicals used were of reagent grade and distilled water was used throughout this study. All equipment required for this study was used in the laboratory of the Central Campus of Technology, Dharan.

2.2. Processing Methods to Reduce Antinutrients

2.2.1. Soaking

Seeds (100 g) were soaked in tap water at a ratio of 1:10 (w/v) at room temperature for 18 h. The soaked seeds were washed twice with ordinary water, rinsed with distilled water, and dried in an oven at 60 °C to a constant weight. The dried samples were ground and stored in an airtight plastic container for further analysis [11].

2.2.2. Open Cooking

The soaked seeds weighing 100 g (12 h in tap water) were cooked in beakers at seed-to-water ratios of 1:5 and 1:6 (w/v) for soaked and unsoaked seeds, respectively. The water

was allowed to boil before the seeds were added. The seeds were boiled until their soft texture was felt between the fingers. The cooked samples were then mashed and dried in a cabinet dryer maintained at 60 °C, finely ground, and stored [11].

2.2.3. Autoclaving

Seeds weighing 100 g were soaked for 12 h, and 100 g of unsoaked seeds were also taken. Both seed samples were autoclaved for 15 min at 121 °C and 2.68 kg/cm. The ratio of seed to water was 1:5 (w/v) for unsoaked seeds and 1:4 (w/v) for soaked seeds. The autoclaved seeds were then mashed, dried at 60 °C, finely ground, and stored [11].

2.2.4. Germination

Seeds (100 g) were soaked overnight in fresh water for 12 h. The seeds were then rinsed, and the water was drained. The seeds were allowed to sprout in an incubator at 30 °C for 36 h. The sprouted samples were dried in a cabinet dryer at 60 °C, finely ground, and stored in an airtight plastic container for further analysis [11].

2.2.5. Roasting

Roasting of mungbean seeds (250 g) was performed in a dryer with sand at 160 °C for 15 min. Roasted seeds were dried at 60 °C, finely ground, and stored in an airtight container for further analysis [11].

2.2.6. Dehulling

Hulls of mungbean (50 g) were removed manually after soaking the mungbean seeds for 12 h in distilled water (1:10, w/v). The dehulled seeds were dried at 60 °C in a hot-air oven, finely ground, and stored [11].

2.3. Analytical Methods

2.3.1. Proximate Analysis of Mungbean

Moisture Content

Moisture content was determined using the hot-air oven method. The sample (5 g) was weighed and heated to a constant weight in an insulated oven at 110 °C. The difference in weight was the amount of evaporated water [12].

Protein Content

Crude protein was determined using the Kjeldahl method, and total protein was calculated by multiplying the nitrogen content by a factor of 6.25 [12].

Fat Content

The fat content of the samples was determined using a Soxhlet apparatus, as described in AOAC [12].

Ash Content

The ash content was determined by incinerating mungbean (5 g) in a muffle furnace at 525 °C for 4–6 h [12].

Crude Fiber Content

For the analysis of crude fiber, the standard method of AOAC [12] was followed.

Carbohydrate Content

The total carbohydrate content of the samples was determined using the difference method [12].

$$\text{Carbohydrate (\%)} = 100 - \%[\text{sum of protein, total ash, fiber, moisture, and fat}] \quad (1)$$

2.3.2. Physical Analysis of Mungbean

Thousand-Kernel Weight

The 1000-kernel weight of mungbean was determined by measuring the weight of 1000 kernels of mungbean seeds after selecting the appropriate sample size using the quartering method [13].

Bulk Density

Bulk density was measured by pouring the seeds into a funnel-shaped hopper. The hopper was centered over the measuring bushel, the hopper valve was opened quickly, and the grains were allowed to flow freely into the measuring bushel. Once the bushel was full, the excess material was leveled off with gentle zigzag strokes using a standard seedburo striking stick. The filled measuring bushel was then weighed, and the mass of grains in the bushel was determined by subtracting the mass of the measuring bushel [14].

Length-to-Breadth Ratio

The length-to-breadth (l/b) ratio of mungbean seeds was determined as mentioned by Unal, Isık [15].

2.4. Determination of Oxalate

The sample (0.1 g) was mixed with 30 mL of 1 M HCL. Each mixture was shaken in a water bath at 100 °C for 30 min. To each mixture, 0.5 mL of 5% $CaCl_2$ was added and thoroughly mixed to precipitate out calcium oxalate. The suspension was centrifuged at 3000 rpm for 15 min, and the supernatant was separated. The pellet was washed twice with 2 mL of 0.35 M NH_4OH and then dissolved in 0.5 M H_2SO_4. The solution was then titrated with a standard solution of 0.1 M $KMnO_4$ at 60 °C to a faint violet color [16].

2.5. Determination of Phytate

The sample (0.2 g) was placed in a 250-mL conical flask. It was soaked in 100 mL of 20% concentrated HCl for 3 h and the sample was then filtered. The filtrate (50 mL) was placed in a 250 mL beaker, and 100 mL of distilled water was added to the sample. Then, 10 mL of 0.3% ammonium thiocyanate solution was added as an indicator and titrated with a standard iron (III) chloride solution containing 0.00195 g of iron per 1 mL [17].

$$\%\text{Phytic acid} = \frac{\text{Titer value} \times 0.00195 \times 1.19 \times 100}{2} \quad (2)$$

where Titer value is measured in mL.

2.6. Determination of Tannin

Colorimetric estimation of tannins is based on the measurement of the blue color formed by the reduction of the Folin–Ciocalteu reagent by tannin-like compounds under alkaline conditions. The mungbean seeds, weighing 0.5 g, were boiled with reflux for 30 min with 40 mL of water. Then they were cooled, transferred to a 50-mL volumetric flask, and diluted to mark. The mixture was shaken and filtered. Aliquots (0 to 1 mL) of the standard tannic acid solution were placed in test tubes, and 7.5 mL of distilled water was added to each tube. Then, 0.5 mL of Folin–Ciocalteu reagent and 1 mL of Na_2CO_3 solution were added, and the volume was adjusted to 10 mL. Finally, color was measured after 30 min at 760 nm against an experimental blank adjusted to zero absorbance [12].

2.7. Determination of Total Phenolic Content

A fresh ground sample weighing 1 g was extracted by 25 mL of methanol; the extracts were shaken in a water bath shaker at room temperature for 24 h. The extract was filtered through Whatmann No. 1 filter paper and the filtrate was stored at 4 ± 2 °C. Then, 0.5 mL of the filtrate solution was mixed with 2.5 mL of Folin–Ciocalteu reagent, and 5 min later, 2.5 mL of Na_2CO_3 (7.5% w/v) was added. The mixed sample was incubated at 45 °C for

45 min. The absorbance was measured at 765 nm against a reagent blank. A standard calibration plot was generated using the known concentrations of gallic acid. The phenolic concentrations in the test samples were calculated from the calibration plot and expressed as mg of gallic acid equivalent (GAE)/100 g of dry sample [18].

2.8. Determination of Saponin

The spectrophotometric method was used for the saponin analysis [19]. A finely ground sample (1 g) was weighed into a 250-mL beaker, and 100 mL of isobutyl alcohol was added. The mixture was shaken for 2 h to ensure uniform mixing. Thereafter, the mixture was filtered through Whatmann No. 1 filter paper into a 100-mL beaker, 20 mL of a 40% saturated solution of magnesium carbonate was added, and the mixture was made up to 250 mL in a 250-mL standard flask. The mixture obtained with saturated $MgCO_3$ was again filtered through a Whatmann No. 1 filter paper to obtain a clear colorless solution. One milliliter of the colorless solution was pipetted into a 50-mL volumetric flask, 2 mL of a 5% $FeCl_3$ solution was added, and the remaining volume was made up with distilled water. The solution was allowed to stand for 30 min to develop a blood-red color. From the stock solution of saponin, 0–10 ppm standard saponin was prepared. The standard solutions were treated in a similar manner with 2 mL of 5% $FeCl_3$. The absorbance of the sample and the standard saponin solution was read after color development on a spectrophotometer at a wavelength of 380 nm.

$$\text{Saponin} = \frac{\text{Absorbance of sample} \times \text{dil.factor} \times \text{gradient of standard graph}}{\text{sample weight} \times 10,000} \quad (3)$$

where sample weight is measured in g.

2.9. Statistical Analysis

The chemical analyses of each sample were performed in triplicates. The data obtained from this study were subjected to analysis of variance (ANOVA) and considered at a 95% confidence level using the statistical software GenStat, version 14.2.0.6297. Tukey's post-hoc test was used to determine the significant difference between means. Values are presented as mean ± standard deviation.

3. Results and Discussion

3.1. Physical Properties of Mungbean

The physical properties of the mungbean were determined. The results obtained are presented in Table 1. The thousand-kernel weight of mungbean seeds was found to be 17.5 g, which is significantly lower than the findings by Imran, Khan [13] (i.e., 46.96 g). This may be because of the different varieties. However, the obtained data was in the range of 7.2–60.1 g as reported by Dahiya, Linnemann [20]. The value of the length-to-breadth (l/b) ratio of the raw mungbean seed was found to be 1.34. Dahiya, Linnemann [20] reported the l/b ratio and bulk density of mungbean seeds to be 1.31–1.38 and 67.9–82.1 kg/hL, respectively. Similar results were reported by Unal, Isık [15]. The value of the bulk density of mungbean varies according to quality, variety, and moisture content of the mungbean [21].

Table 1. Physical properties of mungbean.

Physical Properties	Mungbean Seeds
l/b ratio	1.34 ± 0.02
Bulk density (kg/hL)	75.34 ± 0.25
1000-kernel weight (g)	17.5 ± 0.4

3.2. Proximate Composition of Mungbean

The proximate composition of raw mungbean is given in Table 2. The protein content in the mungbean was found to be 26.78%. Similar values were reported by Mubarak [22]

and Skylas, Molloy [23]. Kavitha, D'souza [11] reported protein to be 31.34%, whereas Nwokolo and Smartt [24] found the protein content in the mungbean to be 23.6%. The crude fiber content of raw mungbean was found to be 4.78%, which was comparable to the data obtained by Mubarak [22] (i.e., 4.63%). The crude fiber content in raw mungbean seed ranges from 3.8 to 6.15% [20]. The ash content of raw mungbean was found to be 3.71%, which was similar to the data obtained by Mubarak [22] (i.e., 3.76%) and Kavitha, D'souza [11] (i.e., 3.5%). The fat content of raw mungbean was found to be 1.52%, which was in the range of 0.17–5.82% as given by Dahiya, Linnemann [20]. The carbohydrate content of raw mungbean was found to be 51.89%, which was similar to the data obtained by Oburuoga and Anyika [25] (i.e., 53.38%) and Onwurafor, Onweluzo [26] (i.e., 52.54%), but the value was much lower than that obtained by Mubarak [22] (i.e., 62.35%).

Table 2. Proximate composition of raw mungbean.

Parameters	Values (%)
Moisture	11.33 ± 0.36
Crude protein (wet basis)	26.78 ± 1.10
Crude fat (wet basis)	1.52 ± 0.31
Crude fiber (wet basis)	4.78 ± 0.23
Ash (wet basis)	3.71 ± 0.46
Carbohydrate (wet basis)	51.89 ± 1.92

3.3. Antinutrients Present in Raw Mungbean

The mean values of the different antinutrients determined are presented in Table 3. The tannin content in the raw mungbean was found to be 476.81 mg/100 g, which was greater than the data obtained by Mubarak [22] (i.e., 330 mg/100 g), and lower than the value obtained by Kavitha, D'souza [11] (i.e., 963 mg/100 g). The oxalate content in the mungbean was 227.46 mg/100 g, which was higher than the findings by Oburuoga and Anyika [25] (i.e., 128.27 mg/100 g). The phytate in the raw mungbean was 626.54 mg/100 g, which was almost similar to the value obtained by Kavitha, D'souza [11] (i.e., 622 mg/100 g), but the value was lower than the range of 727–940 mg/100 g reported by Bindu, Ashwini Meeshi [27]. Total phenol content was found to be 771.75 mg/100 g, which was lower than the findings of Kataria, Chauhan [28] (i.e., 808 mg/100 g), whereas it was in the range of 290–820 mg/100 g as given by Dahiya, Linnemann [20]. The saponin content of the mungbean was found to be 2848 mg/100 g, which was comparable to the values obtained by Kataria, Chauhan [28], but significantly higher than the value obtained by Sivakumaran, Herath [29] (i.e., 1276 mg/100 g). It is concluded that the antinutrient values of mungbean vary according to variety and/or cultivar, climatic conditions, locations, irrigation conditions, types of soil, the year during which they are grown, and storage conditions, as discussed by Nikolopoulou and Grigorakis [30].

Table 3. Antinutrients and phytochemicals in raw mungbean (mg/100 g).

Antinutrients	Values in Dry Basis (mg/100 g)
Tannin	476.81 ± 13.38
Oxalate	227.46 ± 11.67
Phytate	626.54 ± 18.5
Total phenolic content	771.39 ± 15.3
Saponin	2617.59 ± 54.6

3.4. Effects of Different Processing Methods on the Tannin Content of Mungbean

The effects of soaking, germination, roasting, cooking, and dehulling on the tannin content of mungbean were studied. All the treatments significantly reduced ($p < 0.05$) the tannin content of the mungbean seeds, but to varying extents. Dehulling had a more

pronounced effect than other treatments on the reduction in tannin contents. The effects of different processing methods on the tannin content of mungbean are shown in Table 4.

3.4.1. Effects of Roasting

The effects of roasting on the tannin content of mungbean were studied. The values obtained showed that there was a significant reduction ($p < 0.05$) in tannin content, which was reduced from 476.81 mg/100 g to 376.79 mg/100 g after roasting (a 20.97% reduction). Comparable results were observed by Kavitha, D'souza [11]. They found that a significant decrease in tannin content was observed by roasting lentils (i.e., a 16.9% reduction). El-Gohery [31] concluded that roasting lima bean seeds reduces tannin content by 29.5%. Attou, Bouderoua [32] reported that roasting the seeds of lentils reduced the tannin content by 41.41%. The tannin content of chickpea was reduced by 57% due to roasting [33]. Tannin is a heat-stable compound, so roasting has less effect on reducing tannin in the beans than other domestic processing methods.

3.4.2. Effects of Germination

The tannin content of raw mungbean was determined, and the value obtained showed that there was a significant reduction ($p < 0.05$) in tannin content, which reduced from 476.81 mg/100 g to 299.34 mg/100 g after germination (i.e., a 37.22% reduction). Kakati, Deka [34] found that there was a 39.68% reduction in tannin and a 28.14% reduction in tannin content in the SGC 16 and SGC 20 varieties of mungbean, respectively. The reduction in tannin content in mungbean was found to be 66.7% by Mubarak [22]. The reduction in tannin content after germination may be attributed to the leaching-out effect during hydration [35]. Kavitha, D'souza [11] also found that tannin content was reduced by 65.3% after germination.

3.4.3. Effects of Soaking

The tannin content of the raw mungbean was found to be 476.81 mg/100 g. This study showed that soaking significantly decreased ($p < 0.05$) tannin content from 476.81 mg/100 g to 297.21 mg/100 g (i.e., a 37.67% reduction). The results obtained in this study are in line with those obtained by Mubarak [22], who reported a reduction of 38.2% after 12 h of soaking of mungbean. The reduction in tannin content in mungbean after 6 h, 12 h, and 18 h was found to be 3%, 10%, and 15.7%, respectively [11]. Abbas and Ahmad [1] reported that there was a 39.4% reduction in tannin content after soaking for 18 h. The loss of tannin content after soaking may be attributed to leaching out into soaking water under the concentration gradient [35].

3.4.4. Effects of Dehulling

The tannin content of mungbean was found to be significantly reduced ($p < 0.05$) from 476.81 mg/100 g to 174.21 mg/100 g (a 63.46% reduction) after the dehulling process. Our study showed that the highest reduction in tannin content in mungbean was seen in the dehulled sample. Mubarak [22] reported that dehulling the seeds reduced the tannin content in mungbean by 33.34%. Removal of seed coats lowered the tannin content of beans by 68–95% [36], since tannins are mainly located in the seed coat of beans. The reduction in tannin content in horse gram was found to be 89.46–92.99% [37]. Oburuoga and Anyika [25] found that tannin content was reduced by 58.2% by the dehulling process in mungbean seeds.

3.4.5. Effects of Cooking

The effect of open cooking for 15 min on the total tannin content of mungbean was studied. Different samples were cooked with a regulated amount of water, such that no water was drained after cooking. The value obtained showed that there was a significant reduction ($p < 0.05$) in tannin content, which reduced from 476.81 mg/100 g to 269.55 mg/100 g, 195.49 mg/100 g, 252.1 mg/100 g, 184.57 mg/100 g for raw open cooked,

soaked open cooked, raw autoclaving, and autoclaving of soaked seeds, respectively. This study found that autoclaving of soaked seeds reduced 61.49% of tannin content, which was the most effective method, followed by soaked open cooked (a 59% reduction), raw autoclaving (a 47.12% reduction), and raw open cooked (a 43.47% reduction). The effects of cooking methods on tannin content are presented in Table 4.

Mubarak [22] studied the effects of cooking on tannin content in mungbean ranges from 45.5 to 55.5% reduction, where maximum reduction was reported after autoclaving, then open cooking. Kavitha, D'souza [11] also stated that the tannin content in mungbean was significantly reduced after open cooking for 30 min at 100 °C and autoclaving for 15 min at 121 °C. The tannin content in chickpea was reduced by 48% after cooking [38]. Ali, Awadelkareem [39] reported that the effect of cooking on tannin content in different varieties of faba bean ranged from 37.6 to 78%. According to Kaur, Dhawan [40], the cooking and autoclaving of rice bean reduced the tannin content by 27% and 30%, respectively.

Table 4. Effects of different processing methods on tannin content.

Processing Methods	Tannin (mg/100 g)
Raw sample	476.81 ^{a} ± 13.4
Roasting	376.79 ^{b} ± 12.9
Germination	299.34 ^{c} ± 12.6
Soaking	297.21 ^{c} ± 11.5
Dehulling	174.21 ^{e} ± 11.3
Cooking	
Raw open cooking	269.55 ^{c} ± 10.7
Raw autoclaving	252.1 ^{cd} ± 12.2
Soaked open cooking	195.49 ^{de} ± 12.7
Autoclaving of soaked seeds	184.57 ^{e} ± 11.9

Values with same letter are not significantly different ($p < 0.05$) at 5% level of significance.

3.5. Effects of Different Processing Methods on the Oxalate Content of Mungbean

The effects of soaking, germination, roasting, open cooking, autoclaving, and dehulling on the oxalate content of mungbean were studied. All the treatments significantly reduced ($p < 0.05$) the oxalate content of the mungbean seeds, but to varying extents. The combination treatment, i.e., autoclaving of soaked seeds, had a more pronounced effect than other treatments in reducing the oxalate content. The effects of different processing methods on the oxalate content are given in Table 5.

3.5.1. Effects of Roasting

The effects of roasting on the oxalate content of mungbean were studied. The value obtained showed that there was a significant reduction ($p < 0.05$) in oxalate content, which was reduced from 227.46 mg/100 g to 194.69 mg/100 g after roasting (i.e., a 14.41% reduction). It has been reported that the oxalate content of Bambara groundnut is reduced by 8–10% after roasting the groundnut for 15 min at 130 °C in hot sand [41].

3.5.2. Effects of Soaking

Soaking shows a considerable decrease in the oxalate content of mungbean and has been documented as an effective treatment to remove antinutritional factors in legumes. The result showed that soaking significantly reduced ($p < 0.05$) total oxalate content, which was reduced from 227.46 mg/100 g to 172.44 mg/100 g (i.e., a 24.19% reduction). Soaking the seeds in distilled water significantly decreased the contents of total oxalate in the range of 17.40–51.89% [42]. Patel and Dutta [16] reported a reduction of 19.65% in finger millet. The reduction in oxalic acid during soaking and germination may be due to the leaching of oxalate oxidase and oxalate decarboxylase. Similar results for the reduction in oxalic acid content of soaked grains were reported by Brudzyński and Salamon [43].

3.5.3. Effects of Dehulling

The oxalate content of the raw mungbean was found to be 227.46 mg/100 g. This study showed that soaking significantly decreased ($p < 0.05$) oxalate content from 227.46 mg/100 g to 146.74 mg/100 g (i.e., a 35.49% reduction). Pal, Bhartiya [37] reported that the decrease in the amount of oxalic acid content ranged from 456.69 mg/100 g in raw to 301.56 mg/100 g after dehulling of horse gram (i.e., a 33.86% reduction in total oxalate content).

3.5.4. Effects of Germination

The effects of germination on the oxalate content of mungbean were studied. The value obtained showed that there was a significant reduction ($p < 0.05$) in oxalate content, which was reduced from 227.46 mg/100 g to 95.98 mg/100 g after germination (57.8% reduction). Virginia et al. [44] found a significant reduction ($p < 0.05$) in oxalate content during the germination of green pea (65.26%). Similar results were obtained by Patel and Dutta [16], i.e., a 54.36% reduction in finger millet. Pal et al. [37] found that a significant decrease in oxalate content was observed in the initial hours of germination, i.e., 24 h, followed by a non-significant change in the later stages, and the oxalate content of raw horse gram was 466 mg/100 g, which decreased to 308 mg/100 g (i.e., a 33.91% reduction) during 18 h of germination and 341 mg/100 g (i.e., a 26.82% reduction) during 12 h of germination. The decrease in oxalate content during germination is because of the activation of oxalate oxidase, which breaks down oxalic acid into carbon dioxide and hydrogen peroxide, consequently releasing calcium [37].

3.5.5. Effects of Cooking

The effects of cooking on the oxalate content of mungbean were studied. It showed a significant reduction ($p < 0.05$) in the oxalate content ranging from 227.46 mg/100 g to 91.68 mg/100 g, 69.39 mg/100 g, 80.65 mg/100 g, and 66.34 mg/100 g for samples of raw open cooked, soaked open cooked, raw autoclaving, and autoclaving of soaked seeds, respectively. This study found that autoclaving of soaked seeds reduced 70.83% of oxalate content, which was the most effective method, followed by soaked open cooked (a 69.39% reduction), raw autoclaving (a 64.54% reduction), and raw open cooked (a 59.69% reduction). The effects of cooking methods on oxalate content are presented in Table 5. According to Akhtar et al. [45], the reduction in total oxalate content of presoaked cooking was 66.15% of soyabean. The loss of soluble oxalate content in water was considered to be the primary factor contributing to total oxalate reduction.

Table 5. Effects of different processing methods on oxalate content.

Processing Methods	Oxalate (mg/100 g)
Raw sample	$227.46^{a} \pm 11.8$
Roasting	$194.69^{b} \pm 18.2$
Soaking	$172.44^{c} \pm 9.6$
Dehulling	$146.74^{d} \pm 10.9$
Germination	$95.98^{e} \pm 16.5$
Cooking	
Raw open cooking	$91.68^{e} \pm 8.7$
Raw autoclaving	$80.65^{f} \pm 7.9$
Soaked open cooking	$69.39^{g} \pm 7.4$
Autoclaving of soaked seeds	$66.34^{g} \pm 8.6$

Values with same letter are not significantly different ($p < 0.05$) at 5% level of significance.

3.6. Effects of Different Processing Methods on the Phytate Content of Mungbean

The effects of soaking, germination, roasting, open cooking, autoclaving, and dehulling on the phytate content of mungbean were studied. All the treatments significantly reduced ($p < 0.05$) the phytate of the mungbean seeds, but to varying extents. Germination had a

more pronounced effect than the other treatments in the reduction of phytate contents. The effects of different processing methods on phytate content are given in Table 6.

3.6.1. Effects of Roasting

The effects of roasting on the phytate content of mungbean were studied. The value obtained showed that there was a significant reduction ($p < 0.05$) in phytate content, which was reduced from 626.53 mg/100 g to 487.46 mg/100 g after roasting (a 22.2% reduction). A significant decrease in phytates was recorded for roasted varieties of lentils (i.e., a reduction up to 63.01%) at 140 °C for 30 min [32]. Similarly, a reduction in the phytic acid of chickpeas was reported at up to 56% [33]. Kavitha et al. [11] reported that the roasting of mungbean seeds was reduced by 29%. Roasting of lima bean seeds helps in the reduction in phytic acid by 40% [31].

3.6.2. Effects of Soaking

The effects of soaking on the phytate content of mungbean were studied, and the value obtained showed that there was a significant reduction ($p < 0.05$) in phytate content. The results showed a great reduction from 626.53 mg/100 g to 452.53 mg/100 g after soaking the mungbean for 18 h (a 27.78% reduction). Mubarak [22] found that soaking mungbean in tap water reduced the phytate content by 26.7%. Kakati et al. [34] reported that the reduction in phytate in SGC 16 and SGC 20 cultivars of mungbean after soaking was 17% and 21%. Similarly, the reduction in mungbean after soaking for 6 h, 12 h, and 18 h was 7%, 11%, and 20%, respectively [11]. The loss of phytic acid in the soaked seeds may be due to the leaching of phytate ions into the soaking water under the influence of the concentration gradient, which governs the rate of diffusion [46].

3.6.3. Effects of Dehulling

The effects of dehulling on the phytate content of mungbean were studied. The value obtained showed that there was a significant reduction ($p < 0.05$) in phytate content, which was reduced from 626.53 mg/100 g to 441 mg/100 g after dehulling (a 29.61% reduction). In a study by Grewal and Jood [46], the reduction in the phytate content of the Asha cultivar of mungbean was 24%. On dehulling, the losses may be because of the removal of the husk. As the husk contained a relatively higher concentration of phytic acid as compared to whole grains, the removal of the husk accounted for a significantly lower phytic acid content in dehulled grains. Mubarak [22] also reported that 21% of the phytic acid was reduced after the dehulling of mungbean. Similar results were reported by Oburuoga and Anyika [25].

3.6.4. Effects of Germination

Germination shows a considerable decrease in the phytate content of mungbean and has been documented as an effective treatment to remove phytic acid from legumes. The results showed that germination significantly reduced ($p < 0.05$) total phytate content, which reduced from 626.53 mg/100 g to 382.71 mg/100 g (i.e., 38.91% reduction). Kavitha, D'souza [11] found that the phytate content in the germinated sample of mungbean was reduced by 38%. Grewal and Jood [46] reported that the reduction in phytate was 33% after germination. The loss of phytic acid during germination may be caused by the hydrolytic activity of the enzyme phytase on inositol and free phosphate.

3.6.5. Effects of Cooking

The effects of phytate content on open cooking and autoclaving of raw and soaked mungbean were studied. The water was not drained after cooking. It showed a significant reduction ($p < 0.05$) in the phytate content range from 626.53 mg/100 g to 418.5 mg/100 g, 394.53 mg/100 g, 429.92 mg/100 g, and 406.64 mg/100 g for samples of raw open cooked, soaked open cooked, raw autoclaving, and autoclaving of soaked seeds, respectively. The findings obtained from this study showed that soaked open cooking reduced 37.03% of

phytate content, which was the most effective method, followed by autoclaving of soaked seeds (a 35.1% reduction), raw open cooked (a 33.2% reduction), and raw autoclaving (a 31.38% reduction). The effects of phytate content on cooking methods are presented in Table 6.

Table 6. Effects of different treatments of phytate content.

Processing Methods	Phytate (mg/100 g)
Raw sample	626.53 ^{a} ± 18.5
Roasting	487.46 ^{b} ± 15.7
Soaking	452.53 ^{c} ± 12.7
Dehulling	441 ^{cd} ± 12.3
Germination	382.71 ^{h} ± 10.4
Cooking	
Raw autoclaving	429.92 ^{de} ± 10.9
Raw open cooking	418.50 ^{ef} ± 15.4
Autoclaving of soaked seeds	406.64 ^{fg} ± 12.8
Soaked open cooking	394.53 ^{gh} ± 13.6

Values with same letter are not significantly different ($p < 0.05$) at 5% level of significance.

The reduction in phytic acid after boiling was greater than after autoclaving raw mungbean [22]. This study also showed that soaked open cooking had a higher reduction than other methods. In the mungbean cultivars SGC 16 and SGC 20, upon cooking, the reduction in phytate was 33% and 35% [34]. The decrease might be attributed to the leaching of the phytic acid into soaking water under the influence of the concentration gradient, which governs the rate of diffusion. It has been reported that the reduction rates in autoclaving of soaked seeds and soaked open cooking were similar at about 31%, and raw autoclaving and raw open cooking were also similar at about 21% [11].

3.7. Effects of Different Processing Methods on Total Phenolic Content of Mungbean

The effects of soaking, germination, roasting, open cooking, autoclaving, and dehulling on the total phenolic content of mungbean were studied. All the treatments significantly reduced ($p < 0.05$) the total phenolic content of the mungbean seeds, but to varying extents. Dehulling had more effect than the other treatments on the reduction in total phenolic content. The effects of different processing methods on total phenolic content are given in Table 7.

3.7.1. Effects of Roasting

The effects of roasting on the total phenolic content of mungbean were studied. The value obtained showed that there was a significant reduction ($p < 0.05$), which was reduced from 771.39 mg/100 g to 598.78 mg/100 g after roasting (i.e., a 22.38% reduction). Mendoza, Barroga [47] reported that roasting mungbean seeds reduced the polyphenol content by 17%. Roasting, which involves dry heat, could bring about a change in the chemical reactivity of the polyphenols. Roasting decreased the polyphenol content of black bean by 8% [48].

3.7.2. Effects of Germination

The effects of germination on the total phenolic content of mungbean were studied. The value obtained showed that there was a significant reduction ($p < 0.05$) in total phenolic content, which was reduced from 771.39 mg/100 g to 573.49 mg/100 g after germination (a 25.65% reduction). According to Grewal and Jood [46], the polyphenol content of the Asha cultivar of the mungbean seed was reduced by 32% after germination. Before germination, soaking was performed, and some loss of polyphenol during soaking was also expected because of its leaching into the soaking water. A further decrease in polyphenols during germination may be ascribed to the presence of polyphenol oxidase and enzymic

hydrolysis [49]. They reported that the polyphenol in chickpea was reduced by 23% after germination.

3.7.3. Effects of Soaking

The effects of soaking on the total phenolic content of mungbean were studied, and the value obtained showed that there was a significant reduction ($p < 0.05$) in total phenolic content. The result showed a reduction from 771.39 mg/100 g to 494.79 mg/100 g after soaking the mungbean for 18 h (i.e., a 35.88% reduction). In a study conducted by Tajoddin, Manohar [50], they reported that the reduction in polyphenol in soaked mungbean seeds was 32%. The loss of polyphenols during soaking may be due to the leaching out of soluble polyphenolic compounds in soaking water. Grewal and Jood [46] also reported that the polyphenol contents of mungbean seeds were reduced by 23% after soaking for 18 h.

3.7.4. Effects of Dehulling

Dehulling shows a considerable decrease in the total phenolic content of mungbean and has been documented as an effective treatment to remove antinutritional factors in legumes. This result showed that dehulling significantly reduced ($p < 0.05$) total phenolic content, which was reduced from 771.39 mg/100 g to 358.78 mg/100 g (i.e., a 53.48% reduction). According to Tajoddin, Shinde [51], the reduction in polyphenol content in the mungbean of ten cultivars after dehulling was 14–52%. The polyphenol content of Asha variety of mungbean was reduced by 29% after dehulling [46].

3.7.5. Effects of Cooking

The effects of cooking on the total phenolic content of mungbean were studied. It showed a significant reduction ($p < 0.05$) in total phenolic content ranging from 771.39 mg/100 g to 406.65 mg/100 g, 380.91 mg/100 g, 454.76 mg/100 g, and 410.6 mg/100 g for samples of raw autoclaving, autoclaving of soaked seeds, raw open cooked, and soaked open cooked, respectively. This study found that autoclaving of soaked seeds reduced 50.62% of total phenolic content which was the most effective method, followed by raw autoclaving (a 47.28% reduction), soaked open cooked (a 46.78% reduction), and raw open cooked (a 41.05% reduction). The effects of cooking methods on total phenolic content are shown in Table 7.

The Asha variety of mungbean when cooked and autoclaved reduced total phenol content by 32% and 42%, respectively, and the MHIK-25 cultivar of mungbean after cooking and autoclaving was 29% and 39%, respectively [46]. Polyphenols are reported to be present in higher amounts in colored and darker legume varieties than in pale varieties [52]. Pressure cooking of soaked seeds for 5 min decreased polyphenols to a greater extent as compared to the seeds that were ordinarily cooked after soaking. The effect of pressure cooking was greater when the period of pressure cooking was extended. A decreased amount of polyphenols recovered from cooked seeds could be on account of reduced extractability due to their changed chemical reactivity [35].

Table 7. Effects of different processing methods on total phenolic content.

Processing Methods	Total Phenolic Content (mg/100 g)
Raw sample	$771.39^{a} \pm 15.3$
Roasting	$598.79^{b} \pm 11.8$
Germination	$573.49^{c} \pm 19.6$
Soaking	$494.57^{d} \pm 10.6$
Dehulling	$358.78^{h} \pm 14.7$
Cooking	
Raw open cooking	$454.76^{e} \pm 14.8$
Soaked open cooking	$410.6^{f} \pm 17.5$
Raw autoclaving	$406.65^{f} \pm 9.4$
Autoclaving of soaked seeds	$380.91^{g} \pm 15.8$

Values with same letter are not significantly different ($p < 0.05$) at 5% level of significance.

3.8. Effects of Different Processing Methods on the Saponin Content of Mungbean

The effects of soaking, germination, roasting, open cooking, autoclaving, and dehulling on the saponin content of mungbean were studied. All the treatments significantly reduced ($p < 0.05$) the saponin of the mungbean seeds, but to varying extents. The combination treatment, i.e., autoclaving of soaked seeds, had a more pronounced effect than other treatments in reducing the saponin content. The effects of different processing methods on saponin content are given in Table 8.

3.8.1. Effects of Soaking

The effects of soaking on the saponin content of mungbean were studied, and the value obtained showed that there was a significant reduction ($p < 0.05$) in saponin content. The result showed a great reduction from 2617.59 mg/100 g to 2425.87 mg/100 g after soaking the mungbean for 18 h (a 7.32% reduction). Kataria, Chauhan [28] found a 7% reduction by the soaking of mungbean seeds. They also concluded that raising the time of soaking from 12 to 18 h did not influence the saponin content of the seed to a significant extent. The decrease in the level of saponin in mungbean seeds during soaking may be attributed to leaching out into the soaking water under the concentration gradient. Shi, Arunasalam [53] also found that the soaking of pigeon pea reduced the saponin content to 8%.

3.8.2. Effects of Germination

The effects of germination on the saponin content of mungbean were studied. The value obtained showed that there was a significant reduction ($p < 0.05$) in saponin content, which was reduced from 2617.59 mg/100 g to 2276.54 mg/100 g after germination (a 13.03% reduction). In a study by Kataria, Chauhan [28], the reduction in saponin after the germination of mungbean seeds was 11%. They also reported that enzymic degradation could be a possible explanation for the saponin loss during germination. It was reported that the germination of amphidiploids in mungbean and black gram reduced saponin content by 5–16% [35].

3.8.3. Effects of Dehulling

The effects of dehulling on the saponin content of mungbean were studied. The value obtained showed that there was a significant reduction ($p < 0.05$) in saponin content, which was reduced from 2617.59 mg/100 g to 2244.96 mg/100 g after dehulling (14.23% reduction). According to Shi, Arunasalam [53], the reduction in saponin content was 29% after the dehulling of faba beans. They also reported that saponin was reduced by the concentration gradient during soaking and, after dehulling, was reduced by the removal of the seed coat.

3.8.4. Effects of Roasting

The effects of roasting on the saponin content of mungbean were studied. The value obtained showed that there was a significant reduction ($p < 0.05$) in saponin content, which was reduced from 2617.59 mg/100 g to 2163.51 mg/100 g after roasting (i.e., a 17.35% reduction). Le, Le [48] reported that roasting black bean seeds reduced the saponin content significantly by 20%. The decrease in the saponin content of mungbean by roasting was due to the thermolabile nature of saponin [49].

3.8.5. Effects of Cooking

The effects of cooking on the saponin content of mungbean were studied. It showed a significant reduction ($p < 0.05$) in the saponin content range from 2617.58 mg/100 g to 2394.78 mg/100 g, 2050.29 mg/100 g, 2438.61 mg/100 g, and 2344.90 mg/100 g for samples of raw autoclaving, autoclaving of soaked seeds, raw open cooked, and soaked open cooked, respectively. The findings of this study showed that autoclaving of soaked seeds reduced saponin content by 21.67%, which is the most effective method, followed by soaked open cooking (a 10.42% reduction), raw autoclaving (a 8.51% reduction), and raw

open cooked (a 6.84% reduction). The effects of cooking methods on saponin content are shown in Table 8.

Table 8. Effects of different processing methods on saponin content.

Processing Methods	Saponin (mg/100 g)
Raw sample	2617.59 ^{a} ± 54.6
Soaking	2425.87 ^{b} ± 51.9
Germination	2276.54 ^{de} ± 46.9
Dehulling	2244.96 ^{e} ± 40.8
Roasting	2163.51 ^{f} ± 59.4
Cooking	
Raw open cooking	2438.61 ^{b} ± 48.4
Raw autoclaving	2394.78 ^{bc} ± 42.7
Soaked open cooking	2344.90 ^{cd} ± 45.1
Autoclaving of soaked seeds	2050.29 ^{g} ± 39.2

Values with same letter are not significantly different ($p < 0.05$) at 5% level of significance.

Kataria, Chauhan [28] reported that the reduction in saponin in mungbean after cooking, soaked cooking, autoclaving, and autoclaving of soaked seeds was 6%, 8%, 8%, and 20%, respectively. Grewal and Jood [46] concluded that the thermolabile nature of saponin and the formation of a poorly extractable complex may account for the loss of saponin during cooking. The unsoaked cooking reduced saponin by 4–15%, the soaked cooking reduced saponin by 9–14%, the autoclaving of unsoaked seeds reduced saponin by 12–18%, and the autoclaving of soaked seeds reduced saponin by 23–25% of the amphidiploids of black gram and green gram [35], which was also similar to the obtained data in this study.

4. Conclusions

Mungbean was processed using different methods, including soaking, soaking and dehulling, germination, roasting, raw open cooking, soaked open cooking, raw autoclaving, and autoclaving of soaked seeds. All these processing methods significantly reduced antinutrients. Dehulling was the most effective method for the reduction in tannin content (63%) in mungbean. The most effective way to reduce the phytate content in mungbean was by germinating for 48 h (39%). Autoclaving of the soaked seeds reported maximum reduction in oxalate and saponin, and a considerable amount of reduction in tannin and phytate as compared to dehulling, whereas it reported less effect on total phenolic content than that of dehulling, so it can be considered as the most effective method for reducing the antinutrients of mungbean.

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