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Article

Impact of germination and hydrothermal treatment on nutrient profiles and color characteristics of minor millets (kodo millet, little millet, and barnyard millet)

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Abstract: The impact of different pre-treatment methods, namely germination and hydrothermal treatment, on the proximate and physiochemical properties of kodo millet, barnyard millet, and little millet were investigated in this study. This study involved subjecting these millet varieties to various conditions in each pre-treatment method. In germination, the soaking time was varied with three time periods, which were 4 h, 6 h, and 8 h, followed by germination for 48 h. For hydrothermal treatment, the soaking time and temperature were constant, but the steaming times were 10 min, 15 min, and 20 min. In germination, the protein, moisture, and energy contents increased, while the fat, ash, and carbohydrate contents decreased. In hydrothermal treatment, the protein, fat, and ash contents decreased, while the moisture, energy, and carbohydrate contents increased. In germination, the *L* values increased and the *a* and *b* values decreased, while in hydrothermal treatment, the *L* values decreased and the *a* and *b* values increased. These findings shed light on the effects of these pre-treatment methods on the nutritional and physiochemical composition of millet varieties, providing valuable insights for further research and potential applications in the food industry.

Keywords: millet; germination; hydrothermal; proximate; physiochemical properties

1. Introduction

Issues regarding malnutrition and food security have become pressing global concerns. With the world's population continually on the rise, it is crucial to tackle these challenges to ensure equitable access to food resources. In a world where grain dependence is widespread, ensuring food security remains a critical concern, and millets stand out nutritionally due to their grains being rich in proteins, minerals, flavonoids, polyphenols, and vitamins. Millets have the potential to address micronutrient deficiencies through the enhancement of staple crops via biofortification [1]. Millet is a broad categorization used to describe a diverse collection of cereal crops characterized by their diminutive and coarsely textured grains [2].

The term "millet" is a broad label that encompasses a diverse group of small-seeded cereals. They are not confined to a single species or genus but include several prominent millet genera, such as *Pennisetum*, *Elusine*, *Setaria*, *Panicum*, *Paspalum*, *Eragrostis*, *Echinochola*, and *Digitaria*. Millets hold the distinction of being some of

the earliest cultivated cereals, with their history dating back to the dawn of human civilization [3]. They are denoted as small-seeded, yearly cereal grains that serve as a primary dietary staple for millions of individuals, particularly those residing in arid and semi-arid regions across the globe [4]. The advantages offered by this crop, including its efficient production, short growing season, ability to thrive in arid and harsh climates with temperatures reaching up to 64 ℃, and adaptation to low annual rainfall of 350–400 mm, along with limited irrigation facilities, have garnered attention. These characteristics have positioned it as a resilient and drought-resistant plant [5].

Millets are broadly categorized into major and minor millets based on the scale of their cultivation and usage worldwide [6]. Minor millets comprise a category of grassy plants known for their resilience in drought-prone environments. These millets have the potential to serve as alternatives to major cereal crops, and their nutritional attributes have earned them the title of "nutritious millet" [7]. Numerous chronic diseases and health disorders are attributed to an unbalanced nutritional intake. Millets, apart from their agricultural advantages, are renowned for their exceptional nutritional value, often surpassing or at least equaling that of major cereal crops [8].

There is a gap in comprehensively understanding how germination and hydrothermal treatment influence both the nutrient profiles and color characteristics of millets. The evolving landscape of food science and technology underscores the need for a closer examination of traditional and emerging processing methods. By combining traditional wisdom with modern scientific exploration, this research sought to provide practical insights for consumers, the food industry, and the scientific community for fostering a broader appreciation for the potential of these nutricereals in contemporary diets. Minor millets, including kodo millet, barnyard millet, and little millet, have been recognized as nutritionally dense grains with potential health benefits. Among the various processing techniques, germination and hydrothermal treatment have shown promise for altering the composition of grains. With an increasing focus on health-conscious consumer choices, understanding how processing methods influence the nutrient profile of minor millets is crucial. Investigating the impact of germination and hydrothermal treatment on minor millets can guide the development of innovative and health-focused food products.

2. Materials and methods

2.1. Raw material

In this study, all millets, including barnyard millet, kodo millet, and little millet, were sourced from a local market in Thanjavur, Tamil Nadu, India. These grains underwent a cleaning process, which involved the removal of foreign matters and damaged kernels. Subsequently, these cleaned grains were carefully packed into zip lock polyethylene bags and stored at room temperature (30 ± 2 ℃) in a dry place for further processing and analysis.

2.2. Pre-treatments

2.2.1. Hydrothermal treatment

Cleaned millets at 250 g were taken on the basis of random sampling.

Soaking, steaming and drying

The millets were soaked in water and kept in a hot water bath at 60 ℃ for 3 h. The millets were steamed at three time periods of 10 min, 15 min, and 20 min using the traditional steaming method. The millets were then dried in a hot air oven at 50 ℃ for 4 h.

For the standardization of hydrothermal treatment, the soaking time and temperature were constant for all millets, while variation in steaming time was applied, with the drying temperature remaining the same. The millets, which underwent the variation in hydrothermal treatment, were labeled as follows:

H10K – Steaming for 10 min, kodo millet
H10B – Steaming for 10 min, barnyard millet
H10L – Steaming for 10 min, little millet
H15K – Steaming for 15 min, kodo millet
H15B – Steaming for 15 min, barnyard millet
H15L – Steaming for 15 min, little millet
H20K – Steaming for 20 min, kodo millet
H20B – Steaming for 20 min, barnyard millet
H20L – Steaming for 20 min, little millet

2.2.2. Germination

On the basis of random sampling in separate beakers, 250 g of each millet were taken, labeled, and kept for soaking with a ratio of 1:3 at three time periods of 4 h, 6 h, and 8 h. Then, all millets were germinated in a damp muslin cloth for 24 h. The germinated millet grains (sprouts) were then dried and stored. For the standardization of germination treatment for all three millets, the soaking time was varied while the germination time was constant.

4GK – 4h Soaking, 24h Germination, kodo millet
4GB – 4h Soaking, 24h Germination, barnyard millet
4GL – 4h Soaking, 24h Germination, little millet
6GK – 6h Soaking, 24h Germination, kodo millet
6GB – 6h Soaking, 24h Germination, barnyard millet
6GL – 6h Soaking, 24h Germination, little millet
9GK – 9h Soaking, 24h Germination, kodo millet
9GB – 9h Soaking, 24h Germination, barnyard millet
9GL – 9h Soaking, 24h Germination, little millet

2.3. Determination of fat content

Fat was estimated by weighing a 3–5g dry powdered sample in a thimble, which was then placed in an oil flask to be extracted with hexane for about 3 h. The extract was dried with residue on a hot plate, cooled in a desiccator, and weighed. The fat content was then calculated using the formula:

$$Fat\ (\%) = \frac{Final\ weight - Initial\ weight}{Sample\ weight} \times 100$$

2.4. Determination of protein content

A Kjeldahl apparatus was used to determine the protein content, and the factor used for the conversion of Kjeldahl protein into crude protein was 6.25. The method comprised the addition of 0.2–0.5 g of a millet sample, followed by 1 g of copper sulfate, 5 g of sodium/potassium sulfate, and 10 mL of sulfuric acid in a digestion tube. The sample was then digested at 420 ℃ for 3 h, followed by distillation and titration against 0.1N HCl solution in the presence of a mixed indicator. The total nitrogen content and crude protein were calculated by the following equations:

$$Nitrogen\ content = \frac{((BR - Blank) \times 14.01 \times N)}{Ws \times 1000} \times 100$$

where:

BR = burette reading

N = normality of HCl used

Ws = weight of sample

$$Crude\ protein\ (\%) = Nitrogen\ content\ (\%) \times 6.25$$

where 6.25 represents the multiplication factor.

2.5. Determination of moisture content

The moisture content of each sample was determined by weighing 5 g of the sample in an aluminum moisture can and then the sample was dried at 130 ℃ for 3 h in a hot air oven. The average moisture content was calculated on a wet basis in triplicates and the average moisture content was recorded:

$$Moisture\ content = \frac{Weight\ of\ crucible - Weight\ of\ empty\ crucible}{Weight\ of\ sample} \times 100$$

2.6. Determination of ash content

The method described in De Lima's study [9] was used to calculate the total ash content. A sample weighing 5 g was placed in thoroughly burned crucible and left for three h at 550 ℃ in a muffle furnace to be ash-free. The ash content was determined as follows:

$$Ash\ content = \frac{(Weight\ of\ crucible + Ash) - Weight\ of\ empty\ crucible}{Weight\ of\ sample} \times 100$$

2.7. Determination of color characteristics

The color parameters were denoted by L^*, a^*, and b^* for lightness, redness, and yellowness, respectively and these parameters were measured using a color meter (Colorflex EZ model 4510, Hunter Associates Laboratory, USA) for all comminuted millet samples. The instrument was first calibrated using the standard white and green board and then the sample in a Petri dish were evaluated. The color difference was calculated by the given equation:

$$\Delta E = \sqrt{(L - L^*)^2 + (a - a^*)^2 + (b - b^*)^2}$$

where L = Lightness of native sample

a = Redness of native sample
b = Yellowness of native sample
L^* = Lightness of treated sample
a^* = Redness of treated sample
b^* = Yellowness of treated sample

2.8. Statistical analysis

Minitab-17 was used as the statistical tool to perform all statistical analysis, and the samples were analyzed in triplicates. The analysis was performed using the one-way analysis of variance (ANOVA) with Tukey's honest significant difference for comparing the means at a difference of significance level at 95%.

3. Results and discussion

3.1. Effect of processing on protein content of millets

After germination, the protein content significantly increased (**Table 1**) in all millet samples. This substantial rise could be attributed to the biological processes that occur during germination. During this process, enzymes were activated to break down stored nutrients within the seed. As a result, some amino acids were produced in excess of that required for immediate protein synthesis, leading to the accumulation of these amino acids in a free amino acid pool. This accumulation contributed to the overall increase in protein content [10]. Similar results during germination on white finger millet were observed by Hassan et al. [11] at 30 °C for 48 h. Additionally, the decrease in protein content in the germinated millets could be attributed to the loss of water-soluble nitrogen during seed soaking before sprouting. Also, some of the protein was used for the growth and development of the embryo, which can result in reduced protein content.

After subjecting the millets to the hydrothermal treatment, a significant ($p < 0.05$) decrease in protein content (**Table 2**) was observed. The decrease in protein content in hydrothermally treated, decorticated samples could be attributed to the leaching out of soluble protein and appeared to be linked to the drying temperature used after the treatment. Higher drying temperatures likely cause more cellular disruption, leading to a greater loss of protein content, allowing cell contents to leak into the soaking medium [12].

Table 1. Nutritional components of germinated millets (%).

Samples	4GK	4GB	4GL	6GK	6GB	6GL	8GK	8GB	8GL
Moisture (%)	11.24 ± 0.01^{bc}	9.63 ± 0.40^{a}	11.01 ± 0.38^{b}	11.74 ± 0.22^{e}	10.21 ± 0.27^{cd}	11.22 ± 0.76^{bc}	11.95 ± 0.59^{e}	10.70 ± 0.36^{d}	11.55 ± 0.10^{cd}
Protein (%)	8.42 ± 0.53^{a}	11.48 ± 0.79^{a}	7.80 ± 0.54^{a}	8.42 ± 0.65^{a}	11.82 ± 0.59^{a}	7.84 ± 0.43^{a}	8.45 ± 0.53^{a}	11.94 ± 0.25^{a}	7.90 ± 0.32^{a}
Fat (%)	3.50 ± 0.60^{abc}	2.97 ± 0.70^{bc}	5.13 ± 0.80^{a}	3.43 ± 0.72^{abc}	2.69 ± 0.85^{c}	5.06 ± 0.66^{a}	3.36 ± 0.31^{abc}	2.52 ± 0.87^{c}	4.92 ± 0.52^{ab}
Ash (%)	3.03 ± 0.15^{a}	2.73 ± 0.15^{bc}	1.38 ± 0.02^{e}	2.87 ± 0.06^{ab}	2.50 ± 0.10^{cd}	1.36 ± 0.02^{e}	2.60 ± 0.10^{bcd}	2.41 ± 0.09^{d}	1.32 ± 0.02^{e}
Carbohydrate (%)	74.01 ± 0.88^{ef}	72.18 ± 1.72^{f}	74.08 ± 0.66^{def}	77.55 ± 0.92^{ab}	76.78 ± 1.52^{abcd}	74.52 ± 0.20^{cdef}	78.83 ± 0.34^{a}	77.24 ± 0.57^{abc}	75.61 ± 0.78^{bcde}

Table 1. (*Continued*).

Samples	4GK	4GB	4GL	6GK	6GB	6GL	8GK	8GB	8GL
Energy (kcal)	361.19 ± 3.54^{de}	349.41 ± 3.60^{e}	373.66 ± 3.54^{abc}	374.72 ± 3.07^{cd}	362.65 ± 4.10^{cd}	374.98 ± 5.75^{ab}	379.41 ± 3.69^{a}	364.15 ± 5.98^{bcd}	378.30 ± 2.73^{a}

Notes: Means having same alphabet superscript did not show any significant difference among treatments within variety ($p \leq 0.05$).

Table 2. Nutritional components of hydrothermally treated millets (%).

Samples	H10K	H10B	H10L	H15K	H15B	H15L	H20K	H20B	H20L
Moisture (%)	10.81 ± 0.20^{de}	9.14 ± 0.71^{ab}	10.85 ± 0.09^{a}	11.07 ± 0.50^{cd}	9.57 ± 0.49^{e}	11.23 ± 0.13^{bc}	11.85 ± 0.73^{bc}	9.88 ± 0.42^{bc}	11.43 ± 0.71^{e}
Protein (%)	8.24 ± 0.36^{abc}	10.05 ± 0.75^{a}	7.73 ± 0.45^{bc}	8.14 ± 0.88^{abc}	9.55 ± 0.94^{ab}	7.70 ± 0.65^{c}	8.10 ± 0.22^{bc}	9.21 ± 0.49^{abc}	7.48 ± 0.51^{c}
Fat (%)	3.11 ± 0.66^{ab}	3.09 ± 0.34^{ab}	4.88 ± 1.00^{a}	2.98 ± 0.44^{b}	3.04 ± 0.58b	4.41 ± 0.53^{ab}	2.95 ± 0.65^{b}	2.91 ± 0.72^{b}	4.39 ± 0.61^{ab}
Ash (%)	3.27 ± 0.06^{bc}	2.67 ± 0.12^{e}	1.40 ± 0.03^{f}	3.40 ± 0.10^{b}	3.00 ± 0.10^{d}	1.49 ± 0.01^{f}	3.90 ± 0.10^{a}	3.07 ± 0.15^{cd}	1.55 ± 0.01^{f}
Carbohydrate (%)	74.88 ± 1.12^{abc}	71.70 ± 1.75^{c}	71.91 ± 1.41^{bc}	74.21 ± 1.86^{abc}	75.27 ± 0.63^{ab}	74.16 ± 0.45^{abc}	73.10 ± 0.43^{bc}	72.93 ± 1.51^{bc}	77.15 ± 0.78^{a}
Energy (kcal)	363.24 ± 2.42^{bcd}	374.80 ± 3.12^{de}	383.29 ± 4.98^{bcd}	367.40 ± 0.99^{cde}	386.60 ± 1.30^{bc}	387.17 ± 3.13^{b}	371.74 ± 0.64^{e}	394.74 ± 3.13^{de}	398.01 ± 1.92^{a}

Notes: Means having same alphabet superscript did not show any significant difference among treatments within variety ($p \leq 0.05$).

3.2. Effect of processing on fat content of millets

The fat content exhibited a notable decrease ($p < 0.05$) with prolonged soaking and germination, a trend supported by the findings of Saleh et al. [13] on foxtail millet after germination. This decline in fat content could be attributed to lipid hydrolysis and fatty acid oxidation during the germination process. The use of fat as an energy source during germination is another reason for the decrease in fat content [14]. The noteworthy decrease in fat composition could perhaps be associated with increased enzyme activity during germination and the use of fat as an energy substrate. Additionally, the lower fat content in malted flour may increase shelf life by lowering the chance of rancidity, perhaps as a result of enzyme activity in the flour, as proposed by Yenasew and Urga [15].

In hydrothermal treatment, the fat content was observed to decrease significantly (**Table 2**) with extended steaming time. Consistent with this, the fat content also decreased with higher drying temperatures, as indicated by Parnsakhorn and Langkapin [16]. These findings support the notion that fat content diminishes as steaming time and drying temperature increase.

3.3. Effect of processing on ash content of millets

The process of germination led to a noticeable reduction in ash content, as depicted in **Table 1**. This phenomenon has been observed in various studies, where an increase in germination time was linked to a decline in mineral content. The need for minerals could be the cause of this drop in ash content during germination, according to multiple sources [17]. Consequently, the ash content decreased when compared with those of unprocessed grains. Furthermore, mineral leaching that occurs during steeping and washing, as noted by Kumar et al. [18], could be another factor contributing to this decrease during germination.

The ash content was observed to decrease (**Table 2**) in comparison with those of raw samples. Steaming pressure was identified as a factor affecting ash content [19].

Interestingly, the ash content increased with longer steaming times. This can be explained by the leaching of soluble minerals from the millet grains into the surrounding water or steam. Prolonged steaming provided more contact time with water or steam, facilitating the dissolution and removal of minerals from the grains.

3.4. Effect of processing on moisture content of millets

The moisture content significantly increased ($p < 0.05$) in all samples after germination (**Table 1**) compared with that of the control non-germinated sample, as depicted in **Table 3** [20]. This rise in moisture content during germination was attributed to the absorption of moisture by whole grains from the soaking medium, which is essential for initiating metabolic processes, consequently influencing the grain's structure. With longer soaking times, a greater number of cells within the seeds became hydrated. A similar increase in moisture content was observed in finger millet by Banusha and Vasantharuba [21], who proposed that this increase was due to the hydration of millet seeds during soaking and germination. Furthermore, during germination, changes in the grain's structure, known as sorption isotherm, can make it more attractive to water, further contributing to increased moisture content.

The moisture content increased significantly ($p < 0.05$) when compared with those of the raw samples. Increased moisture content can encourage the rapid growth of mold, which is a sign that the grain will not last as long in storage [22]. According to Maldaner et al. [23], water in the grain moves from the center to the surface during rest, which facilitates the removal of water from the drying chamber.

Table 3. Nutritional composition of raw samples (%).

Samples	CK	CB	CL
Moisture (%)	10.04 ± 0.34^{a}	9.00 ± 0.29^{b}	10.81 ± 0.16^{a}
Protein (%)	8.27 ± 0.06^{b}	11.18 ± 0.25^{a}	7.80 ± 0.10^{a}
Fat (%)	3.57 ± 0.15^{b}	3.47 ± 0.32^{b}	5.33 ± 0.15^{a}
Ash (%)	3.43 ± 0.15^{a}	2.80 ± 0.10^{b}	1.42 ± 0.03^{c}
Carbohydrate (%)	73.47 ± 0.52^{a}	73.46 ± 0.43^{a}	74.63 ± 0.12^{a}
Energy (kcal)	359.03 ± 2.19^{c}	370.12 ± 2.73^{b}	377.73 ± 1.47^{a}

Notes: Means having same alphabet superscript did not show any significant difference among treatments within variety ($p \leq 0.05$).

3.5. Effect of processing on carbohydrate content of millets

The changes in carbohydrate content during germination could be attributed to the utilization of carbohydrates as an energy source for embryonic growth. Carbohydrate values were observed to decrease ($p < 0.05$) in the case of barnyard millet and little millet, and this could be likely due to the consumption of carbohydrates for sprout metabolism [24]. However, kodo millet displayed a significant increase ($p < 0.05$) in carbohydrate content when compared with those of raw samples [25]. Changes in the other food components of moisture, fat, protein, ash, and crude fiber may also had an impact on the change in the amount of carbohydrates during germination.

In the context of hydrothermal treatment, the carbohydrate content experienced a significant increase as the drying temperature was raised [26]. Several factors could contribute to this increase, including the gelatinization of starch, condensation of sugars, loss of water weight, or leaching of soluble carbohydrates. During a hydrothermal treatment, especially steaming, the starch granules within millet grains undergo gelatinization, causing them to swell and rupture, making the starch more soluble and accessible. This process results in a higher carbohydrate content, as the starch becomes more readily measurable. Extended steaming could lead to the condensation of simple sugars present in millets. As water is removed through steaming, the sugars become more concentrated, contributing to a higher carbohydrate content in the remaining material. Additionally, during steaming, water within the millet grains evaporates, further influencing carbohydrate concentration.

3.6. Effect of processing on energy values of millets

The energy values exhibited notable changes, with a significant increase observed in kodo millet but a significant decrease in barnyard millet and little millet, which are consistent with the findings reported by Ocheme and Chinma [27], where pearl millet also showed a decline in energy value after 48 h of germination. The breakdown of starch granules by amylase into simpler, more water-soluble sugars was responsible for this change in energy content. During germination, these simple sugars provided the developing embryo with energy. It was possible that the decreased fat content played a role in lowering the energy content [28].

In the context of treatment time, a significant ($p < 0.05$) increase in energy content was observed in all millets. This rise in energy content could be attributed to the concentration of macronutrients, including carbohydrates, proteins, and fats. As these macronutrients make a significant contribution to the caloric content of food, their increased concentration leads to a higher energy value. Similar to its effect on carbohydrate content, the gelatinization of starch during steaming also plays a role in boosting energy content. This process makes the starch more accessible and contributes to the overall energy content of millets.

3.7. Effect of processing on physiochemical properties of millets

The L, a, b, and ΔE values for the color of the raw samples are represented in **Table 4**, while the color values for the germinated samples and hydrothermally treated samples are presented in **Table 5** and **Table 6**, respectively.

In germinated millets, referring to **Table 5**, the L values was found to be in line with the results of Hejazi and Orsat [29] and Nefale and Mashau [30], who reported that the L values of millets were observed to increase after germination. The L values of the raw samples were 41.19 ± 0.06 for kodo millet, 59.95 ± 0.55 for barnyard millet, and 51.99 ± 0.41 for little millet. There were increases from 49.46 ± 0.62 to 51.01 ± 0.54 for kodo millet, 61.77 ± 0.21 to 62.05 ± 0.18 for barnyard millet, and 55.23 ± 0.44 to 55.73 ± 0.27 for little millet, respectively. The a values were found to decrease as compared with those of the raw samples. The a values in the raw samples were 5.30 ± 0.20, 3.27 ± 0.08, and 4.01 ± 0.07 for kodo millet, barnyard millet, and little millet, respectively. The values decreased from 3.93 ± 0.09 to 3.73 ± 0.13 for kodo millet,

from 3.28 ± 0.01 to 3.01 ± 0.03 for barnyard millet, and from 3.56 ± 0.06 to 3.54 ± 0.03 for little millet. The study's result showed similarities to that of Hejazi and Orsat [29], who reported that the *a* value was observed to decrease in germinated flour as compared with that of ungerminated flour. The *b* values were observed to decrease as compared with those of the raw samples. The *b* values of the raw samples were 8.65 ± 0.11 for kodo millet, 12.85 ± 0.09 for barnyard millet, and 12.02 ± 0.08 for little millet. The decrease in *b* values ranged from 7.74 ± 0.08 to 7.04 ± 0.24 for kodo millet, from 12.80 ± 0.07 to 12.11 ± 0.02 for barnyard millet, and from 12.00 ± 0.03 to 11.89 ± 0.07 for little millet, respectively.

For the hydrothermally treated samples, referring to **Table 6**, the *L* values decreased in all millets, which were from 41.19 ± 0.64 to 36.31 ± 0.33 for kodo millet, from 59.95 ± 0.55 to 51.41 ± 0.10 for barnyard millet, and from 51.99 ± 0.41 to 45.30 ± 0.16 for little millet. As steaming time increased, the values decreased to 34.80 ± 0.19 from 36.31 for kodo millet, 49.67 ± 0.06 from 51.41 ± 0.10 for barnyard millet, and 44.97 ± 0.05 from 45.30 ± 0.16 for little millet. The *a* values increased from 5.30 ± 0.20 to 5.42 ± 0.04 for kodo millet, from 3.7 ± 0.08 to 3.81 ± 0.05 for barnyard millet, and from 4.01 ± 0.07 to 4.23 ± 0.04 for little millet. With the increase in steaming temperature, the values also increased to 34.80 ± 0.19 from 51.41 ± 0.10 for kodo millet, 4.12 ± 0.02 from 4.23 ± 0.04 for barnyard millet, and 4.49 ± 0.02 from 5.70 ± 0.14 for little millet. Similarly, there was an increase in *b* values with the increase in steaming time, which ranged from 8.65 ± 0.11 to 8.64 ± 0.02 for kodo millet, from 12.85 ± 0.09 to 12.38 ± 0.10 for barnyard millet, and from 12.02 ± 0.08 to 8.76 ± 0.04 for little millet. These values increased up to 8.77 ± 0.07 from 8.64 ± 0.02 for kodo millet, 14.13 ± 0.02 from 13.64 ± 0.05 for barnyard millet, and 12.59 ± 0.02 from 8.76 ± 0.04 for little millet. Mannuramath and Yenagi [31] reported that the whiteness of hydrothermally treated millet was found to be notably affected by changes in temperature and the duration of soaking and steaming. This treatment process caused a significant alteration in the millet's color, transitioning it from a reddish hue to a deep black shade. This transformation was likely attributed to nonenzymatic browning reactions akin to the Maillard reaction, as suggested by Lamberts et al. [32]. Additionally, another potential factor contributing to this change could be the oxidation of polyphenols, as proposed by Dharmaraj et al. [33].

Table 4. Color values of control samples.

Samples	Kodo millet	Barnyard millet	Little millet
L	41.19 ± 0.064^{c}	59.95 ± 0.55a	51.99 ± 0.41^{b}
A	5.30 ± 0.20^{a}	3.27 ± 0.08^{c}	4.01 ± 0.07^{b}
B	8.65 ± 0.11^{c}	12.85 ± 0.09^{a}	12.02 ± 0.08^{b}
ΔE	0.74 ± 0.53^{a}	0.43 ± 0.18^{a}	0.32 ± 0.13^{a}

Notes: The means having the same alphabet superscript does not show any significant difference among the treatments within the variety ($p \leq 0.05$).

Table 5. Color values of germinated millets.

Samples	4GK	4GB	4GL	6GK	6GB	6GL	8GK	8GB	8GL
L	49.46 ± 0.62^{e}	61.77 ± 0.21^{a}	55.23 ± 0.44^{c}	51.42 ± 0.15^{d}	61.93 ± 0.20^{a}	55.59 ± 0.15^{c}	51.01 ± 0.54^{d}	62.05 ± 0.18^{b}	50.73 ± 0.27^{c}
A	3.93 ± 0.09^{bc}	3.28 ± 0.01^{f}	3.56 ± 0.06^{cd}	3.12 ± 0.12^{a}	3.11 ± 0.05^{ef}	3.55 ± 0.01^{d}	3.73 ± 0.13^{b}	3.01 ± 0.03^{e}	3.54 ± 0.03^{cd}
B	7.74 ± 0.08^{e}	12.80 ± 0.07^{b}	12.00 ± 0.03^{c}	7.58 ± 0.14^{a}	12.72 ± 0.08^{b}	11.92 ± 0.08^{b}	7.04 ± 0.24^{d}	12.11 ± 0.02^{b}	11.89 ± 0.07^{c}
ΔE	8.24 ± 0.62^{b}	10.15 ± 0.17^{a}	9.63 ± 0.56^{a}	1.84 ± 0.20^{d}	1.78 ± 0.200^{d}	0.74 ± 0.16^{e}	3.27 ± 0.44^{c}	3.64 ± 0.15^{c}	3.76 ± 0.26^{c}

Notes: The means having the same alphabet superscript does not show any significant difference among the treatments within the variety ($p \leq 0.05$).

Table 6. Color values of hydrothermally treated millets.

Samples	H10K	H10B	H10L	H15K	H15B	H15L	H20K	H20B	H20L
L	36.31 ± 0.33^{ef}	51.41 ± 0.10^{a}	45.30 ± 0.16^{c}	35.49 ± 0.82^{f}	50.66 ± 0.18^{a}	44.97 ± 0.05^{cd}	34.80 ± 0.19^{e}	49.67 ± 0.06^{b}	44.97 ± 0.05^{cd}
A	5.42 ± 0.04^{a}	3.81 ± 0.05^{f}	4.23 ± 0.04^{cd}	5.70 ± 0.14^{a}	3.96 ± 0.06^{ef}	4.37 ± 0.02^{bc}	5.90 ± 0.06^{a}	4.12 ± 0.02^{de}	4.49 ± 0.02^{b}
B	8.64 ± 0.02^{e}	13.64 ± 0.05^{b}	12.38 ± 0.10^{d}	8.76 ± 0.04^{e}	13.75 ± 0.08^{b}	12.57 ± 0.05^{cd}	8.77 ± 0.07^{e}	14.13 ± 0.02^{a}	12.59 ± 0.02^{c}
ΔE	5.22 ± 0.32^{gh}	6.04 ± 0.81^{fg}	4.74 ± 0.18^{h}	8.59 ± 0.10^{bc}	9.35 ± 0.19^{b}	10.39 ± 0.06^{a}	6.70 ± 0.15^{ef}	7.05 ± 0.05^{de}	7.73 ± 0.11^{cd}

Notes: The means having the same alphabet superscript does not show any significant difference among the treatments within the variety ($p \leq 0.05$).

4. Conclusion

The study demonstrated the effects of pretreatments, which were germination and hydrothermal treatment, on the proximate composition and physiochemical properties of kodo millet, barnyard millet, and little millet. Germination showed distinct impacts on these millets. It led to a reduction in fat content, attributed to the utilization of lipids for energy during sprouting. The ash content dropped, possibly as a result of the leaching of minerals and the removal of roots, shoots, and bran layers. The moisture content notably increased during germination, a result of moisture absorption for metabolic processes and structural changes in the grains. The carbohydrate content exhibited variability, decreasing for barnyard millet and little millet but increasing for kodo millet. This variance may be explained by the utilization of carbohydrates for sprout metabolism. The energy values also changed significantly, with an increase for kodo millet and a decrease for barnyard millet and little millet, influenced by factors such as starch breakdown, fat reduction, and macronutrient concentration. In contrast, the hydrothermal treatment, particularly steaming, affected these millets differently. The carbohydrate content increased with higher drying temperatures, primarily due to the gelatinization of starch, condensation of sugars, and leaching of soluble carbohydrates. This resulted in elevated energy values. Understanding these effects can be valuable for optimizing the processing of these millets, potentially enhancing their nutritional and functional characteristics to meet various culinary and dietary needs. The choice between germination and hydrothermal treatment would depend on various factors, such as the desired nutritional profile, taste, texture, and culinary application of the millets. Further research and experimentation, including vitamins, amino acids, minerals, and other functional compounds, may be needed to determine the most suitable treatment for specific purposes.

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