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# Comparative evaluation of foxtail (*Setaria italica*) and barnyard (*Echinochloa frumentacea*) millets upon germination and roasting on the physicochemical and nutritional properties

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**Abstract**
Millets are nutrient-dense, climate-adaptive cereal grains that have garnered significant interest as sustainable substitutes for traditional cereals due to their nutritional benefits and versatility in various agro-climatic environments. Suitable processing methods, especially germination and roasting can affect the physicochemical and nutritional characteristics of millets, thereby improving their applicability in food product innovation. The current research examined the impact of germination and roasting on the physicochemical and nutritional properties of foxtail millet (*Setaria italica*) and barnyard millet (*Echinochloa frumentacea*), using typical jeerakasala rice as the benchmark grain. Both varieties of millet underwent germination and roasting as separate pretreatments and their qualitative characteristics were assessed and statistically analysed. Marked disparities ($p < 0.05$) were noted across the treatments regarding moisture, fat, protein, ash, calcium, iron, crude fibre, carbohydrate and total solids. Germinated foxtail millet demonstrated the greatest levels of protein (11.63%), crude fibre (2.44%), ash (3.51%) and calcium (87.95 mg/100 g) among the samples assessed. Conversely, germinated barnyard millet had the greatest iron concentration of 6.68 mg/100 g. These results indicate that germination exhibit significant potential for enhancing specific nutritional qualities in grains. The noted compositional variations underscore the necessity of choosing appropriate millet cultivars and preprocessing techniques for certain culinary uses. Moreover, incorporating pretreated millets in conventional culinary recipes could provide avenues for creating nutritionally superior dishes with appealing sensory attributes. The current research endorses the viability of germination and roasting as effective processing methods for expanding millet applications and fostering the creation of value-added, cereal-derived products.

**Keywords:** Barnyard millet, foxtail millet, germination, millet payasam, proximate composition, roasting

## Introduction

Millets are traditional cereal grains that have attracted increasing scientific interest owing to their nutritional value, adaptability to adverse environmental conditions and potential to enhance dietary diversity and food security (Yousaf *et al.*, 2021) [1]. They provide carbohydrates, proteins, lipids, dietary fibre, minerals, vitamins and bioactive compounds, although their composition and nutrient bioavailability vary with genotype, growing conditions and post-harvest processing (Jenipher *et al.*, 2024) [2]. Pretreatments such as soaking, germination, roasting, fermentation and milling can modify the nutritional composition, digestibility, functional properties and antinutritional factors (Sharma *et al.*, 2018) [3]. Foxtail millet (*Setaria italica*) is an important minor millet containing proteins, dietary fibre, lipids, minerals and essential amino acids. Its protein content is generally reported to be higher than that of rice, though considerable variation exists among genotypes and cultivation conditions (Hou *et al.*, 2022; Kalsi & Bhasin, 2023) [4, 5]. The SIA 3088 genotype has been identified as a promising source of iron, highlighting its potential for nutritional improvement through appropriate processing (Shobana *et al.*, 2025) [6]. Barnyard millet (*Echinochloa frumentacea*) is another nutritionally valuable minor millet also containing carbohydrates, proteins, dietary fibre, minerals and phytochemicals (Sasi *et al.*, 2026) [7]. Comparative studies have reported differences in protein, fibre, fat, ash, calcium and iron contents between these millets and rice, indicating their potential as alternative cereal grains (Kalita *et al.*, 2025) [8]. Germination can be considered as a bioprocessing technique that activates endogenous enzymes and initiates metabolic changes in cereal grains, potentially influencing nutrient composition, digestibility, antioxidant activity and antinutritional factors. On the other hand, roasting is a dry-heat treat



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ment that can also alter the physicochemical and nutritional characteristics of grains through changes in moisture content, nutrient composition, phenolic compounds and antioxidant activity. The extent of these changes depends on the grain type and processing conditions. Furthermore, the distribution of nutrients within the grain influences its nutritional quality. Although previous studies have investigated the effects of processing on the nutritional properties of millets, literature is lacking in the comparative assessment of germinated and roasted millets against jeerakasala rice, which is important for the substitution of basmati rice in traditional desserts like payasam to make it diabetic-friendly and rich in many nutrients. The two grains selected for the study have similar cooking parameters. The work was undertaken to evaluate the physicochemical and nutritional properties of germinated and roasted foxtail and barnyard millets in comparison with raw rice without any pretreatments.

## Materials and Methods

### *Materials*

Good quality seeds of foxtail millet (*Setaria italica*) and barnyard millet (*Echinochloa frumentacea*) with husk were procured from the Indian Institute of Millets Research (IIMR), Hyderabad. The foxtail millet variety used in the study was SIA 3088 and the barnyard millet was DHBM-93-3. Jeerakasala rice was used as the control. The grains were manually cleaned to remove soil, stones, weed seeds and damaged or insect-infested ones and were stored in airtight containers until processing. The study consisted of five experimental groups: $T_1$ (germinated foxtail millet), $T_2$ (germinated barnyard millet), $T_3$ (roasted foxtail millet), $T_4$ (roasted barnyard millet) and $T_5$ (jeerakasala Rice).

### *Methods*

The grains were manually cleaned to remove stones, dust, immature grains and plant residues. It was then washed with potable water before both the pretreatments.

### *Germinated millet*

The cleaned grains were soaked separately at a millet-to-water ratio of 1:2 (w/v) for 12 h at 25 ± 2 ℃, after which excess water was drained off. Soaked grains were spread uniformly on clean, moistened muslin cloth and kept under ambient conditions at 25 ± 2 ℃ for 48 h for germination. Germinated grains were transferred to trays, dried at 60 ± 2 °C to a moisture content of approximately 5-6%, cooled to room temperature. The emerged rootlets were removed manually. The grains were then de-husked using a semi-automatic millet de-husker (Model MDI3/MRD3; 3 HP single-phase electric motor; capacity: 300–500 Kg/h) manufactured by Sri Balaji Industries, Coimbatore, Tamil Nadu.

### *Roasted millet*

Cleaned grains were put in millet de-husker wherein the husk was loosened by pressure and friction and after that they were removed by an aspirator. The de-husked grains were roasted at 110 ± 5 ℃ for 5-6 minutes and cooled to room temperature and stored in air-tight containers for further study.

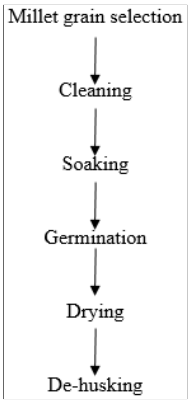



**Figure 1.** Preparation of Germinated millet grains

### *Physicochemical and nutritional analysis*

Moisture, protein, ash and crude fibre were determined using AOAC methods 925.10, 984.13, 923.03 and 978.10 respectively. Carbohydrate was calculated by difference and total solids was determined gravimetrically. Energy was calculated using atwater factors (4 kcal/g protein, 9 kcal/g fat and 4 kcal/g carbohydrate). Fat was determined by the procedure followed by (Sharma *et al.*, 2016) [9] while calcium and iron content were determined as per (Wafula *et al.*, 2018) [10] and phosphorus was determined by the method of AOAC, 2012 [11].

### *Statistical analysis*

All the experimental data obtained in the study was subjected to one-way analysis of variance (ANOVA) at 5% level of significance. Tukey's honestly significant difference (HSD) test was used for post-hoc comparison. SPSS software version 24 was used for the analysis.

## Results and Discussion

### *Physicochemical and nutritional analysis*

All the analysis were done in three independent trials and the observations are represented in Table 1.

Values are mean ± SD ($n$ = 3). $T_1$-Germinated foxtail millet, $T_2$-Germinated barnyard millet, $T_3$-Roasted foxtail millet, $T_4$-Roasted barnyard millet, $T_5$-Jeerakasala rice. Different superscript letters within a row indicate significant differences by Tukey's HSD test ($p < 0.05$), ** Significant at 0.01 level, ns = non-significant

**Table 1.** Physicochemical and nutritional characteristics

| Parameter | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | *F*-value |
|---|---|---|---|---|---|---|
| Moisture (%) | 5.52 ± 0.34$^{a}$ | 5.24 ± 0.06$^{ab}$ | 4.38 ± 0.43$^{bc}$ | 3.95 ± 0.12$^{c}$ | 9.64 ± 0.49$^{d}$ | 136.49** |
| Fat (%) | 3.41 ± 0.74$^{a}$ | 3.00 ± 0.50$^{ab}$ | 3.33 ± 0.70$^{ab}$ | 1.81 ± 0.62$^{bc}$ | 1.01 ± 0.05$^{c}$ | 10.01** |
| Protein (%) | 11.63 ± 0.95$^{b}$ | 8.91 ± 0.10$^{a}$ | 9.99 ± 0.40$^{ab}$ | 8.28 ± 0.03$^{a}$ | 8.84 ± 0.94$^{a}$ | 9.98** |
| Ash (%) | 3.51 ± 0.62$^{c}$ | 2.19 ± 0.25$^{a}$ | 1.93 ± 0.58$^{a}$ | 2.19 ± 0.18$^{a}$ | 0.69 ± 0.04$^{b}$ | 18.34** |
| Calcium (mg/100 g) | 87.95 ± 0.05$^{d}$ | 74.70 ± 0.10$^{c}$ | 39.00 ± 8.00$^{a}$ | 43.00 ± 2.00$^{a}$ | 17.17 ± 0.15$^{b}$ | 180.25** |
| Iron (mg/100 g) | 4.50 ± 0.10$^{ab}$ | 6.68 ± 0.00$^{d}$ | 3.47 ± 0.81$^{a}$ | 4.70 ± 0.42$^{ab}$ | 1.60 ± 0.20$^{c}$ | 58.13** |
| Phosphorus (mg/100 g) | 312.00 ± 42.57 | 293.67 ± 152.78 | 267.00 ± 11.27 | 245.05 ± 10.95 | 219.33 ± 5.77 | 0.80$^{ns}$ |
| Crude fibre (%) | 2.44 ± 0.27$^{d}$ | 1.27 ± 0.08$^{c}$ | 0.44 ± 0.02$^{b}$ | 0.39 ± 0.01$^{ab}$ | 0.07 ± 0.01$^{a}$ | 177.26** |
| Carbohydrate (%) | 72.56 ± 0.63$^{b}$ | 80.02 ± 0.64$^{a}$ | 80.01 ± 0.74$^{a}$ | 82.75 ± 0.75$^{c}$ | 79.74 ± 1.31$^{a}$ | 60.15** |
| Total solids (%) | 94.48 ± 0.34$^{a}$ | 94.76 ± 0.06$^{a}$ | 95.62 ± 0.43$^{bc}$ | 96.05 ± 0.12$^{c}$ | 90.36 ± 0.49$^{d}$ | 136.69** |

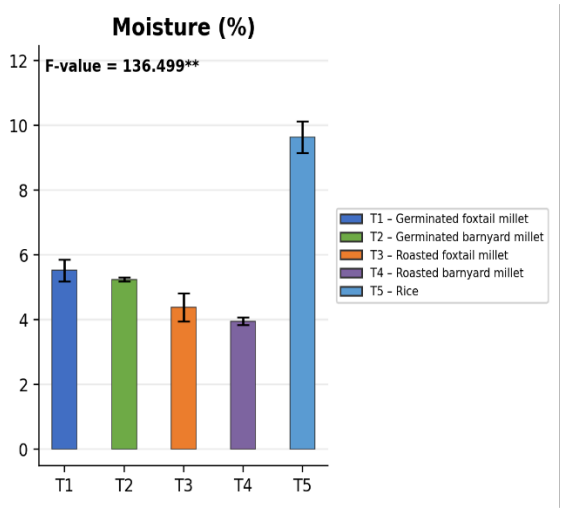
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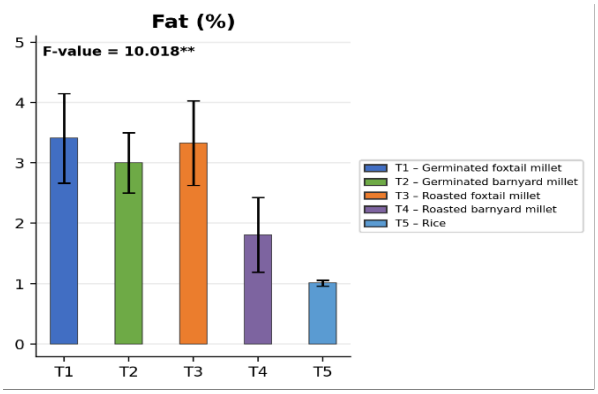
| Parameter | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | *F*-value |
|---|---|---|---|---|---|---|
| Energy (kcal/100 g) | 367.45 | 382.72 | 389.97 | 380.41 | 360.21 | $0.99^{ns}$ |

### *Moisture*




A notable disparity in moisture levels was observed during the roasting and germination, succeeded by the drying ($F$ = 136.499, $p$ < 0.01). $T_5$ demonstrated the greatest moisture percentage of (9.64 ± 0.49), followed by $T_1$ (5.52 ± 0.34), $T_2$ (5.24 ± 0.06%), $T_3$ (4.38 ± 0.43%) and $T_4$ (3.95 ± 0.12%) respectively. The minimal moisture levels in foxtail and barnyard millet could result from the elevated temperatures causing water evaporation during direct dry-heat processing. Conversely, germinated millets experience regulated rehydration throughout the steeping process prior to being exposed to the gentle drying conditions that maintain residual moisture inside the seed structure as described by (Bachate *et al.*, 2025) [12]. When moisture evaporates from the seed matrix, the relative concentration of the remaining components increases (total solids) correspondingly (Mohd *et al.*, 2023) [13].

### *Fat*



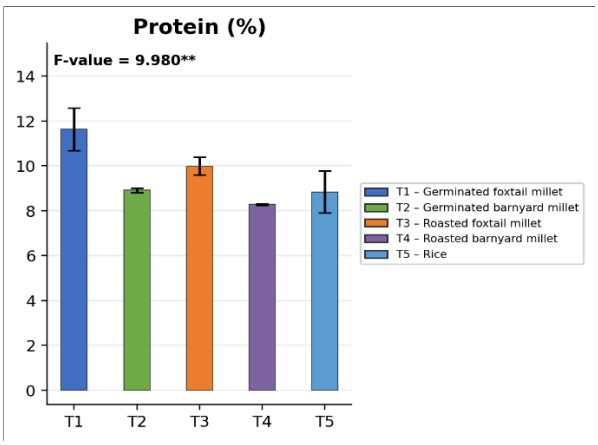

A significant difference in fat content was noted in the study. $T_1$ recorded the highest fat content (3.41 ± 0.74%), followed by $T_3$ (3.33 ± 0.70%) and $T_2$ (3.00 ± 0.50%). In comparison, $T_4$ (1.81 ± 0.62%) and $T_5$ (1.01 ± 0.05%) exhibited lower fat contents. The relatively higher fat content of foxtail millet may be due to the large and fat-rich germplasm and the higher fat concentration in the bran outer layer (Ameena *et al.*, 2026) [14]. The reduction in the fat content of millets during germination, as compared with roasting, may be due to the thermal destruction of lipids, the formation of unextractable starch-lipid complexes, and the volatilization of fatty acid derivatives during dry heating (Mohd *et al.*, 2023) [13].

### *Protein*

There was a significant difference in the protein content of millet during the roasting process and germination, followed by drying of the foxtail and barnyard millets ($F$ = 9.980, $p$ = 0.0016). $T_1$ exhibited the highest protein content (11.63 ± 0.95%), followed by $T_3$ (9.99 ± 0.40%). While the $T_2$, $T_4$, and $T_5$ exhibited a comparable protein content of 8.91 ± 0.10%, 8.28 ± 0.03%, and 8.84 ± 0.94%, respectively. Germination process increases the protein content in millets, which may be due to the activation of hydrolytic enzymes and amino acid synthesis (Tumwine *et al.*, 2019) [15]. In contrast, dry roasting reduces protein content via thermal protein denaturation, destruction of heat-labile amino acids and the loss of nitrogenous volatile compounds (Bachate *et al.*, 2025) [12]. Moreover, the foxtail millets exhibited a higher protein content than the barnyard millet; multiple proximate studies validate that the foxtail millets maintain a superior crude protein content compared to barnyard millet under identical testing conditions. For example, in a comprehensive evaluation of minor millet flours, foxtail millet flour contained 10.29% crude protein compared to 6.93% in barnyard millet flour and 6.19% in rice flour (Verma *et al.*, 2025). Literature available for foxtail millet (SIA 3088) also shows a relatively high protein content, supporting the nutritional potential of this genotype (Layek *et al.*, 2023) [16].

### *Ash*

Ash gives an overall measurement of inorganic residue but does not directly represent mineral bioavailability of the grain. The ash content of the millets also exhibited a significant difference ($F$ = 18.346, $p$ = 0.0001) during germination and roasting processes. $T_1$ exhibited the highest ash content (3.51 ± 0.62%), whereas $T_5$ showed the lowest ash content (0.69 ± 0.04%) (Table 1). The higher ash concentration of millet relative to rice may be due to the fact that millet grains generally contain more minerals and rice is commonly consumed in its polished form, which removes much of its mineral-rich bran and germ (Li *et al.*, 2025) [17]. Various studies supported the statement that ash declines as the degree of milling increases due to its mineral-rich pericarp, aleurone and bran layers being polished during the milling process. The study by Akhter *et al.* (2023) [18] reported that the ash content of rice is often low after polishing, for example, 0.4–1.48 g/100 g across polished rice varieties and the polishing reduces ash by roughly 42-70% depending on variety and degree of milling. While the millets also lose the ash content during the polishing, which shows that their minerals are commonly concentrated in outer layers, but whole or less-polished millet still retains more ash content than polished rice (Elancheran *et al.*, 2026) [19].

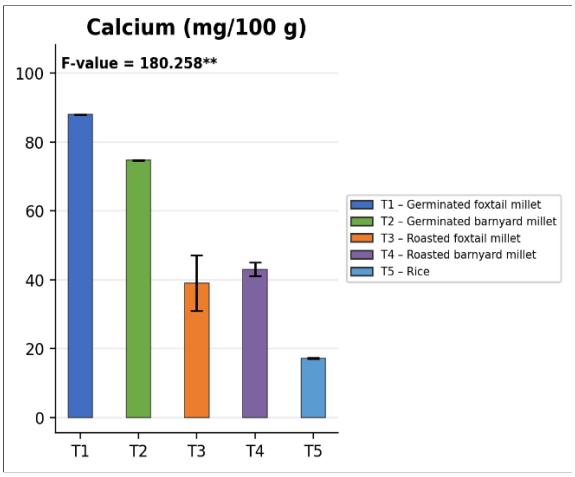



The calcium content also exhibited a significant difference across various treatments ($F$ = 180.258, $p$ < 0.0001). $T_1$ had the highest measured calcium concentration (87.95 ± 0.05 mg/100 g), followed by $T_2$

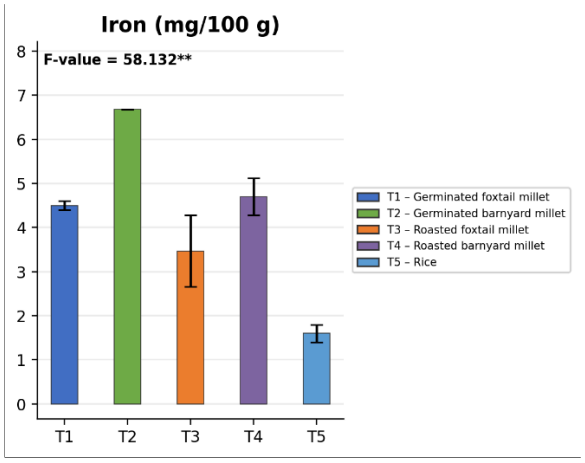


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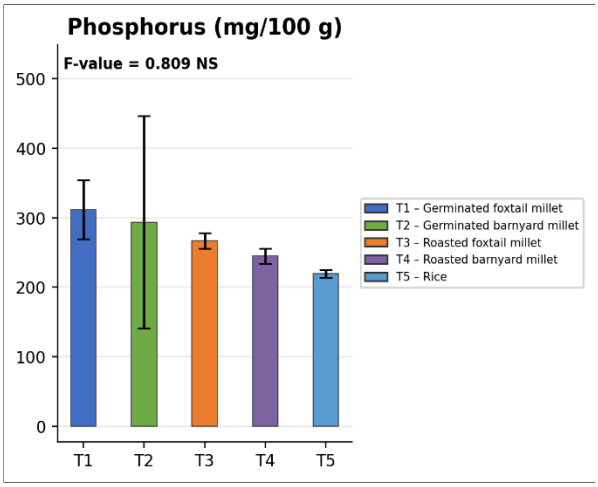
(74.70 ± 0.10 mg/100 g). $T_3$, $T_4$ and $T_5$ contained 39.00 ± 8.00, 43.00 ± 2.00 and 17.17 ± 0.15 mg/100 g, respectively (Table 1). Germination may influence mineral composition by enhancing phytate degradation and modifying the grain matrix, which may potentially affect mineral bioaccessibility. However, the total calcium concentration should not be interpreted as a direct indicator of calcium bioavailability. Germination may improve calcium bioaccessibility in millets through the activation of endogenous phytase, which hydrolyses phytic acid and reduces its ability to bind calcium. Furthermore, structural changes in the grain matrix during sprouting may facilitate the release of calcium from mineral–antinutrient complexes, potentially enhancing its presence. However, these changes do not necessarily increase the total calcium concentration of the grain (Shinde *et al.*, 2023; Magar *et al.*, 2025) [20, 21].




The iron content exhibited significant variation among $T_1$, $T_2$, $T_3$, $T_4$, and $T_5$ ($F = 58.132$, $p < 0.0001$). $T_2$ exhibited the highest value (6.68 ± 0.00 mg/100 g), followed by $T_4$ (4.70 ± 0.42 mg/100 g) and $T_1$ (4.50 ± 0.10 mg/100 g). $T_5$ contained 1.60 ± 0.20 mg/100 g (Table 1). Germination may enhance iron bioaccessibility by promoting phytate degradation and altering the distribution of mineral-containing fractions within the grain (Shobana *et al.*, 2025) [6]. However, total iron content and bioaccessible iron represent distinct parameters, as an increase in mineral bioaccessibility does not necessarily correspond to an increase in total iron content. This distinction is particularly relevant when evaluating foxtail millet genotypes, including SIA 3088 and other millet varieties, in which mineral composition and bioaccessibility may vary depending on genotype and processing conditions (Anitha *et al.*, 2021) [22].

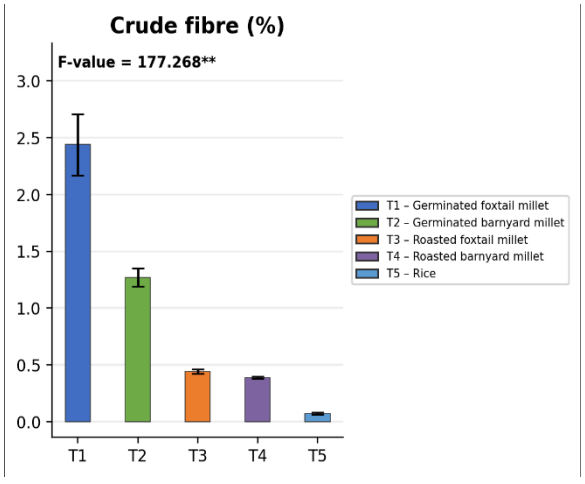



Phosphorus content did not exhibit a statistically significant variation among $T_1$, $T_2$, $T_3$, $T_4$, and $T_5$ ($F = 0.809$, $p = 0.5469$). Although $T_1$ showed the highest numerical phosphorus concentration (312.00 ± 42.57 mg/100 g), the differences among treatments were not statistically significant (Table 1). These observations may suggest that the processing treatments did not produce a detectable effect on the total phosphorus content during the germination and roasting process. Although germination may influence phosphorus availability through phytate degradation and the redistribution of phosphorus containing compounds, these changes do not necessarily alter the total phosphorus concentration (Azeke *et al.*, 2011) [23].




### *Crude fibre*

Crude fibre content exhibited a significant difference across $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$ ($F = 177.268$, $p < 0.0001$). $T_1$ recorded the highest crude fibre content (2.44 ± 0.27%), followed by $T_2$ (1.27 ± 0.08%). While the $T_3$, $T_4$ and $T_5$ exhibited substantially lower values of 0.44 ± 0.02%, 0.39 ± 0.01% and 0.07 ± 0.01%, respectively (Table 1). The higher crude fibre content observed in germinated millets may be associated with changes in the grain matrix and the relative proportions of its constituents during germination. In contrast, the lower values in roasted samples may reflect differences in the inherent grain composition and the effects of thermal processing. The particularly low crude fibre content of jeerakasala rice may be attributable to the removal of fibre-rich outer grain layers during polishing (Zhu *et al.*, 2023) [24].



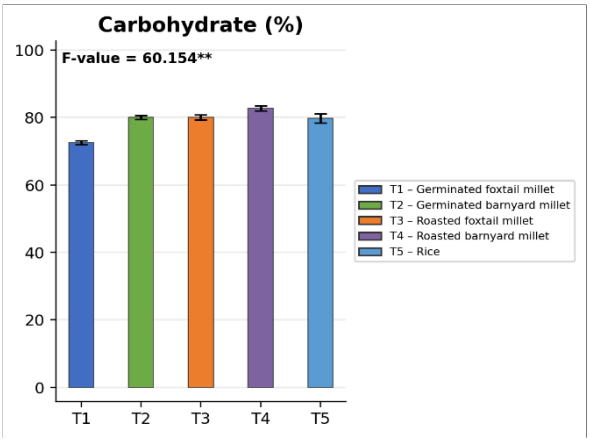

### *Carbohydrate*

The calculated carbohydrate content exhibited highly significant variation among $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$ ($F = 60.154$, $p < 0.0001$). $T_4$ recorded the highest carbohydrate content (82.75 ± 0.75%), whereas $T_1$ exhibited the lowest value (72.56 ± 0.63%). $T_2$ and $T_3$ showed carbohydrate contents of approximately 80%, comparable to that of $T_5$ (79.74 ± 1.31%) (Table 1). The lower carbohydrate content observed in germinated foxtail millet may be associated with the mobilization of stored carbohydrates during germination, when endogenous enzymes hydrolyse starch into simpler sugars that are utilized for respiration and seedling growth (Lu *et al.*, 2025) [25]. Differences between

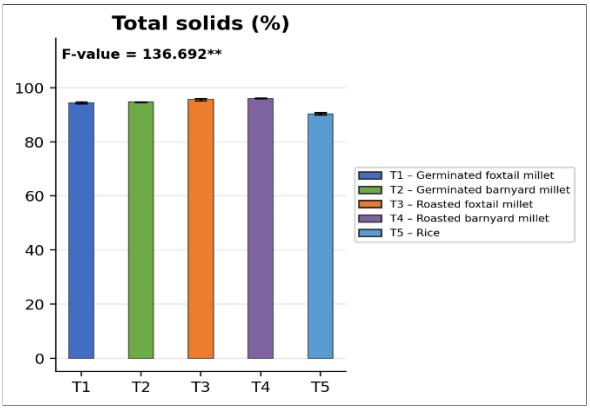


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germinated and roasted samples may also reflect variations in moisture content and the relative proportions of other proximate constituents (Kulkarni *et al.*, 2026) [26].



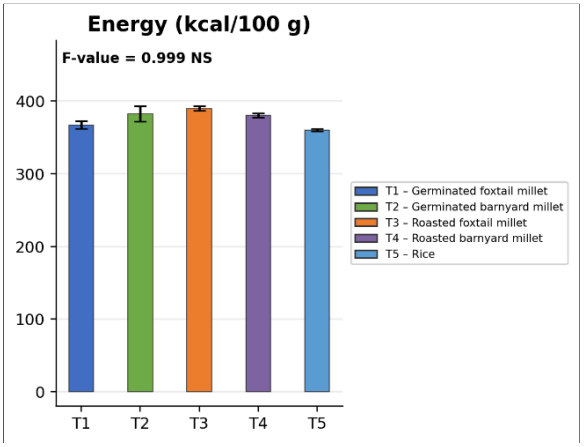

### *Total solids*




Total solids content exhibited highly significant variation among $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$ ($F = 136.692$, $p < 0.0001$). $T_4$ recorded the highest total solids content (96.05 ± 0.12%), followed by $T_3$ (95.62 ± 0.43%). $T_2$ and $T_1$ exhibited total solids contents of 94.76 ± 0.06% and 94.48 ± 0.34%, respectively, whereas $T_5$ recorded the lowest value (90.36 ± 0.49%) (Table 1). The comparatively lower total solids content of germinated foxtail and barnyard millets may be attributed to water absorption during soaking and germination, which increases grain moisture content. In contrast, roasting promotes moisture loss through heat-induced evaporation, resulting in a higher proportion of total solids in the roasted millet samples. However, the final total solids content of germinated millets also depends on the extent of drying following germination (Verma *et al.*, 2015) [27].

### *Energy value*

The calculated energy content varied among $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$, ranging from 360.21 to 389.97 kcal/100 g. $T_3$ exhibited the highest energy value (389.97 kcal/100 g), followed by $T_2$ (382.72 kcal/100 g), $T_4$ (380.41 kcal/100 g), and $T_1$ (367.45 kcal/100 g). $T_5$ recorded the lowest calculated energy value (360.21 kcal/100 g). The relatively higher energy content of roasted foxtail millet may be attributed to its higher fat content (3.33%). Similarly, the energy value of germinated foxtail millet may be influenced by its comparatively high protein content (11.63%) but lower carbohydrate content (72.56%) than the other samples. Calculated energy differences among roasted and germinated foxtail and barnyard millet samples, relative to rice, are consistent with variation in fat, protein, and carbohydrate fractions, because energy is calculated from these proximate components and processing changes them significantly (Nithyashree *et al.*, 2020) [28].




## 4. Conclusion

The present study observed that germination and roasting significantly influenced the physicochemical and nutritional characteristics of foxtail and barnyard millets with variations depending on the millet variety and processing treatment. Germinated foxtail millet exhibited the highest protein, crude fibre, ash and calcium contents, highlighting its potential as a nutrient-rich food ingredient. Germinated barnyard millet recorded the highest iron concentration, indicating its potential contribution to dietary iron intake. In contrast, roasting resulted in reduced moisture content and increased total solids, with roasted barnyard millet exhibiting the lowest moisture and highest total solids and carbohydrate content. Roasted foxtail millet recorded the highest calculated energy value, partly attributable to its fat content. Phosphorus content remained statistically comparable across treatments, suggesting that the processing conditions had no significant effect on its measured concentration. Compared with jeerakasala rice, the millet samples generally exhibited higher concentrations of protein, minerals, and crude fibre, although their nutritional characteristics varied with processing. Overall, germination and roasting represent useful processing approaches for modifying the nutritional profiles of millets and enhancing their potential incorporation into diverse food products. Further investigations should assess mineral bioaccessibility, antinutritional factors, digestibility, and sensory acceptability to establish the suitability of these processed millets for specific food applications.

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