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Evaluation of Physico-Chemical Properties and Nutritional Composition of White Finger Millet (KMR-340) subjected to different pre-treatments

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ABSTRACT

The present study aimed to evaluate and compare the dimensional, physico-chemical, functional, and nutritional properties of white finger millet (Eleusine coracana) against black finger millet, with a focus on the impact of various pre-treatments. These included roasting, popping, malting, and combinations of malting with thermal steaming (TS1, TS2, and TS3). Dimensional analysis revealed that white finger millet exhibited significantly greater width, geometric and arithmetic diameters, surface area, and sphericity, suggesting better grain morphology. Functional properties such as hydration capacity (1.41 g/100 seeds), swelling index (17.57), and seed volume (3.9 ml) were also superior in white millet, indicating enhanced cooking and processing qualities. The proximate analysis demonstrated that malting improved the protein (11.25%) and fibre (5.15%) contents, while roasted and steamed samples showed increased carbohydrate levels (up to 73.11%). Mineral content, particularly calcium (up to 323.66 mg/100g), iron (5.31 mg/100g), and zinc (2.54 mg/100g), was retained or improved through processing. Notably, anti-nutritional factors such as phytates were drastically reduced from 148.66 mg/100g in the raw sample to 49.66 mg/100g in the malt + TS3 sample, and tannins were eliminated across all treatments. The study encountered challenges related to the standardization of combined pre-treatments and ensuring uniform thermal exposure without nutrient loss. Despite these hurdles, the research contributes valuable insights into the optimization of millet processing techniques. These results underline the effectiveness of thermal and biological pre-treatments in enhancing the nutritional and functional profile of white finger millet. Such improvements make it a highly suitable candidate for value-added and health-promoting food formulations, particularly in regions dependent on millets as staple foods. The study supports the incorporation of scientifically optimized pre-treatment methods to boost the bioavailability and health potential of traditional grains.

Keywords: *White finger millet, Pre-treatments, Physico-chemical properties, Functional properties, Nutritional composition and Anti-nutritional factors*

Introduction

Finger millet (*Eleusine coracana*), commonly known as ragi, nachani, or nagli, is one of the major minor millets cultivated and consumed across various regions of India, particularly in the hilly terrains and southern parts of the country. Traditionally consumed in forms such as dumplings, finger millet is recognized for its rich nutritional profile, especially calcium (300–350 mg/100 g), phosphorus (283 mg/100 g), and iron (3.9 mg/100 g) [1,2]

The grain exhibits considerable variation in shape, size, and color—ranging from elliptical to globular forms and colors from greyish-white to deep red. Such physical attributes are critical not only for grain identification but also for the development of equipment used in harvesting, processing, storage, and other post-harvest operations [3]. Moreover, morphological diversity in finger millet, especially grain color, has been associated with differences in nutrient composition, such as protein and calcium content [4]. Although darker varieties are commonly grown, consumer preferences have increasingly shifted towards white grain types due to their higher protein levels, lower fiber and tannin contents, and improved organoleptic properties [5]. As a result, white finger millet has gained popularity, particularly in urban markets and the bakery industry.

In response to this growing demand, a white-grained finger millet variety, KMR-340, was developed by Dr. S.R. Ravishankar at the University of Agricultural Sciences, Bangalore. This variety, released in 2017 from the VC Agricultural Research Centre, Mandya, is a hybrid derived from the parental lines WRT-14 and GE2924. KMR-340 matures within 95–100 days, features white ear heads with incurved fingers, and is suitable for both irrigated and rainfed conditions in Southern Dry Karnataka. It has demonstrated superior yield performance, resistance to blast disease, and adaptability in late Kharif cultivation, outperforming local checks such as KMR-204 and OUAT-2 [6].

Nutritionally, KMR-340 is an excellent source of protein (11.98 g/100 g), calcium (392 mg/100 g), and iron (4.72 mg/100 g), making it a promising candidate for value-added food products, especially in the bakery sector. Studies have shown that bakery products made from KMR-340 possess greater consumer acceptability compared to those prepared using conventional brown finger millet varieties[7].

To further enhance the functional and nutritional attributes of millets, pre-treatment methods such as germination and roasting are widely applied. Germination has been found to

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significantly increase the protein content of finger millet (by up to 72%) and reduce anti-nutritional factors like phytates, thereby improving mineral bioavailability. Roasting, on the other hand, improves carbohydrate (64.24 g/100 g) and fat content (3.64%), alters starch crystallinity, and influences the rheological behavior of millet-based food matrices [6].

Given the growing importance of white finger millet in functional food development and health-oriented diets, the present study aims to evaluate the physico-chemical properties and nutritional composition of the KMR-340 variety subjected to different pre-treatments. This assessment is intended to support its application in various food formulations, particularly in bakery and health-based product development.

2. Materials and Methods

2.1 Processing of White Finger Millet

White finger millet (WFM) grains were meticulously cleaned using potable water to remove dust and extraneous matter. The cleaned grains were then dried in a cabinet dryer at 60 °C for 3 hours until a final moisture content of approximately 11% was achieved. These dried grains were subsequently utilized for all further analyses. For the evaluation of dimensional, physical, and functional properties, WFM was compared with a locally available control variety. Additionally, the grains were subjected to various pre-treatment techniques to assess their effects on nutritional composition and anti-nutritional factors.

2.2 Dimensional properties of White Finger Millet

Dimensional measurements including length, width, and thickness were taken from 10 randomly selected WFM grains using a digital vernier caliper with a precision of 0.001 mm. The average values were expressed in millimeters. Geometric Mean Diameter (GMD) and Arithmetic Mean Diameter (AMD) were calculated according to the method of Mpotokwane et al. (2008) [8]. Square Mean Diameter (SMD) and Equivalent Diameter (EQD) were computed as per the procedure outlined by Gosavi (2022)[9]. Sphericity (%) was derived following the method proposed by Hamdani et al. (2014) [10]. Grain volume and surface area were determined using the formulas described by Karababa and Coşkun (2013) [11], while Aspect Ratio (%) was calculated as per Varnamkhasti et al. (2008)[12].

2.3 Physical and functional properties of White Finger Millet

The physical and functional characteristics of WFM were assessed using standardized analytical protocols. Parameters such as 100-seed weight, volume, hydration capacity, hydration index, swelling capacity, swelling index, and bulk density were determined following the method of William et al. (1983) [13]. Color attributes of the grains were measured using a Lovibond LC 100 spectrocolorimeter paired with the SV 100 test kit. The color metrics recorded included lightness (L*), red/green value (a*), yellow/blue value (b*), chroma (C*), and hue angle (H°), as per the methodology described by Thilagavathi et al. (2015) [14].

2.4 Pre-treatment methods applied to White Finger Millet

To study the influence of various processing methods on WFM, four different pre-treatments were applied. The resulting flours were compared with the untreated control flour, obtained by grinding cleaned WFM grains using a Tata chakki grinder.

2.4.1 Roasting

WFM grains were dry roasted in a pan at 120 °C for 5–7 minutes using the technique described by Obadina et al. (2016) [15].

2.4.2 Malting

The grains were washed five times with clean water and soaked for 5 hours. Excess water was drained, and the grains were wrapped in muslin cloth and weighted (5 kg) to remove residual moisture. Germination was carried out at 27 ± 3 °C for 24 hours, followed by shade drying for 48 hours. The germinated grains were then roasted at 120 °C for 5 minutes and ground into flour using a Tata chakki grinder [16].

2.4.3 Popping

Moisture content of the grains was adjusted to 19% by sprinkling water, followed by thorough mixing. The conditioned grains were sealed in an airtight container and equilibrated for 24 hours. Popping was performed in an iron frying pan maintained at 175–200 °C. The grains were removed from heat once the popping sound ceased [16].

2.4.4 Malting + Moist Steaming

Malted grains were subjected to thermal treatment via moist steaming at 115 °C under 10 psi pressure for 5, 10, and 15 minutes, in accordance withfollowing the procedure outlined by Sajilata et al. (2006) [17].

2.5 Proximate composition, mineral content and anti-nutritional factors

The proximate composition—moisture, protein, fat, ash, and crude fiber—was estimated using standard methods prescribed by AOAC (2007) [18]. Carbohydrate content was calculated by difference. Mineral content, including calcium, iron, zinc, copper, magnesium, phosphorus, and potassium, was analyzed using Atomic Absorption Spectrophotometry (AAS) in accordance withfollowing AOAC (2000) [19]. Anti-nutritional factors were also evaluated. Tannin content was estimated using the modified Vanillin-HCl method in methanol as described by Price et al. (1978) [20], while phytate content was determined using the colorimetric method of Wheeler and Ferrel (1971) [21]. These analyses provided accurate quantification of compounds that influence nutrient bioavailability.

2.6 Statistical analysis

All experimental data were systematically recorded, compiled, and subjected to statistical analysis. Analysis of Variance (ANOVA) was performed to assess the significance of differences across various pre-treatments with respect tofor nutritional and anti-nutritional parameters. Paired t-tests were applied for comparing physical, functional, and dimensional attributes between control and treated samples. All analyses were conducted using appropriate statistical software to ensure robust interpretation and reliability of results [22].

3. Results and Discussion

3.1 Dimensional properties of control and white finger millet

Table 1 presents a comparative analysis of the dimensional properties of white and black finger millet grains. White finger millet exhibited significantly greater width (1.71 ± 0.12 mm vs. 1.47 ± 0.176 mm), geometric mean diameter (1.64 ± 0.09 mm vs. 1.46 ± 0.13 mm), arithmetic mean diameter (1.64 ± 0.09 mm vs. 1.47 ± 0.13 mm), surface volume (2.18 ± 0.34 mm^3 vs. 1.32 ± 0.30 mm^3), and surface area (8.14 ± 0.88 mm^2 vs. 6.23 ± 1.27 mm^2) when compared to black finger millet, indicating statistically significant differences in these traits. The sphericity of white finger millet (92.25 ± 0.25%) was also significantly higher than that of black finger millet (84.4 ± 0.60%), suggesting that the grains of white finger millet are more spherical and symmetrical in shape, which could influence their milling and processing behavior. However, the differences in length (1.76 ± 0.12 mm vs. 1.56 ± 0.13 mm), thickness (1.51 ± 0.05 mm vs. 1.39 ± 0.127 mm), square mean diameter (2.82 ± 0.16 mm vs. 2.17 ± 0.57 mm), equivalent diameter (2.03 ± 0.12 mm vs. 1.70 ± 0.23 mm), and aspect ratio (100.4 ± 0.69% vs. 94.5 ± 0.62%) were found to be statistically non-significant, indicating that both varieties share similar grain proportions in these specific dimensions.

The similar study by Khatoniar and Das (2020) [23] conducted a detailed study on the physical dimensions of black finger millet. Their findings revealed that the length of black finger millet grains was 1.92 mm (± 0.11) and the breadth was measured at 1.73 mm (± 0.02), giving a length-to-breadth ratio of 1.11 (± 0.03). The thickness of the grains was observed to be 1.26 mm (± 0.04). The geometric mean diameter was reported as 1.75 mm (± 0.20), while the arithmetic mean diameter was 1.76 mm (± 0.02). Furthermore, the sphericity of black finger millet grains was calculated to be 91.00 (± 0.01). These dimensions provide valuable insights into the physical properties of black finger millet.

Ramashia et al. (2018) [24] studied the dimensional properties of finger millet (Eleusine coracana) sourced from sub-Saharan Africa. In there their study, the physical dimensions of milky creamy and black finger millet grains showed notable variations. The length of milky creamy millet was observed to be 1.63 mm (± 0.01), significantly greater than the 1.41 mm (± 0.00) measured for black millet. For width, black millet exhibited a slightly larger value of 1.38 mm (± 0.01) compared to 1.28 mm (± 0.01) for milky creamy millet. Similarly, the thickness of black millet, at 1.27 mm (± 0.01), was marginally higher than that of milky creamy millet, which was 1.22 mm (± 0.01). The geometric mean diameter for the two varieties was nearly identical, with milky creamy millet at 1.36 mm (± 0.18) and black millet at 1.35 mm (± 0.06). Likewise, the arithmetic mean diameter followed a similar pattern, with 1.38 mm (± 0.22) for milky creamy millet and 1.35 mm (± 0.07) for black millet. In terms of shape-related properties, the aspect ratio of milky creamy finger millet was 92.21% (± 0.83), significantly higher than the 73.55% (± 0.23) for black millet . As for size-related parameters, the surface area of milky creamy millet was 5.81 mm^2 (± 0.82), slightly larger than the 5.73 mm^2 (± 0.90) observed for black millet. Finally, the volume of milky creamy millet was 0.86 mm^3 (± 0.02), slightly exceeding the 0.82 mm^3 (± 0.16) of black millet. These findings demonstrate subtle differences in the physical dimensions of the two millet varieties, aligning with the results reported by Hamdani et al. (2014) [10].

The dimensional properties of finger millet grains, including length, width, thickness, geometric mean diameter (GMD), arithmetic mean diameter (AMD), square mean diameter (SMD), equivalent diameter, sphericity, surface volume, surface area and aspect ratio, are critical for evaluating their physical characteristics. These parameters significantly influence various aspects of processing, handling and storage. For instance, the individual dimensions of length, width and thickness help in determining the shape and size distribution of the grains, which are crucial for designing sieves and sorting machines. A consistent size distribution facilitates uniformity during processing operations such as milling and dehulling. These findings are supported by Jain and Bal (1997) [25], who emphasized the importance of dimensional properties in designing agricultural processing equipment.

Similarly, GMD provides a single representative value for the grain size, which is essential for assessing sieving and aerodynamic behavior during cleaning and grading processes. The sphericity and aspect ratio of the grains are is vital for understanding their flowability, packing behavior and handling efficiency. High sphericity indicates better flow and reduced friction, which aids in the design of storage systems and transport mechanisms (Mohsenin, 1986) [26]. Surface area and surface volume are equally important, particularly in processes such as drying and chemical treatment, as they determine the grain's exposure to heat and moisture. These parameters influence the rate of moisture loss during drying and the effectiveness of any coating or treatment applied for pest control or storage enhancement (Baryeh, 2002) [27].

Furthermore, the aspect ratio, which describes the elongation of grains, is particularly relevant for maintaining the aesthetic appeal and functional properties of processed products like flour and semolina. These dimensional attributes also provide crucial inputs for designing and optimizing agricultural machinery, including threshers and grinders, to minimize grain loss and breakage during processing[28]. Moreover, they play a role in the assessment of grain quality, which is important for market grading and export standards.

By understanding the relationship between the physical dimensions and functional properties, these parameters contribute to improving processing efficiency, ensuring quality in end products, and minimizing post-harvest losses. Overall, the dimensional properties of finger millet offer valuable insights that can enhance processing techniques, storage systems and overall grain utilization efficiency.

Table 1: Dimensional properties of white finger millet and black finger millet

Dimensional Properties	Black finger Millet	White finger millet	t value
Length(mm)	1.56 ± 0.13	1.76 ± 0.12	2.87 (NS)
Width(mm)	1.47 ± 0.176	1.71 ±0.12	6.99*
Thickness(mm)	1.39 ± 0.127	1.51 ±0.05	2.64 (NS)
Geometric mean Diameter (GMD) (mm)	1.46 ± 0.13	1.64 ±0.09	5.75 *
Arithmetic mean diameter (AMD) (mm)	1.47 ± 0.13	1.64 ±0.09	4.50*
Square mean diameter (SMD((mm)	2.17 ± 0.57	2.82 ± 0.16	2.15 (NS)
Eq diameter(mm)	1.70 ± 0.23	2.03 ± 0.12	3.68 (NS)
Sphericity(mm)	84.4 ± 0.60	92.25 ± 0.25	20.73**
Surface Volume(mm^3)	1.32 ± 0.30	2.18 ± 0.34	6.04*
Surface area (mm^2)	6.23 ± 1.27	8.14 ± 0.88	5.97*
Aspect ratio(%)	94.5 ± 0.62	100.4 ± 0.69	3.52 (NS)

Each value is the average of three determinants
*S- Significant NS-Non Significant * Significant at 5 % ** Significant at 1%*

3.2 Physical and functional properties of white and black finger millet

Table 2 presents a comparative analysis of the physical and functional properties of black and white finger millet. White finger millet showed significantly superior hydration capacity (1.41 ± 0.01 g/100 seeds) compared to black finger millet (0.82 ± 0.05 g/100 seeds), indicating a greater ability to absorb and retain water. Similarly, swelling capacity was significantly higher in white finger millet (0.50 ± 0.05 ml/100 seeds) than in its black counterpart (0.33 ± 0.05 ml/100 seeds). The swelling index also reflected a significant difference, with white millet recording 17.57 ± 0.81 compared to 11.62 ± 0.57 for black, indicating better grain expansion upon hydration.

On the other hand, parameters such as thousand thousand-grain weight (2.86 ± 0.115 g in white vs. 2.4 ± 0.1 g in black), seed volume (3.9 ± 0.1 ml in white vs. 2.9 ± 0.1 ml in black), hydration index (17.11 ± 0.98 in white vs. 13.91 ± 0.80 in black), and bulk density (0.74 ± 0.04 kg/m^3 in white vs. 0.82 ± 0.06 kg/m^3 in black) did not differ significantly. While white finger millet tended to exhibit higher values in these parameters, the variations were not statistically conclusive. In terms of color, white finger millet grains appeared significantly lighter and more vivid. The L* value (57.68 ± 0.05) of white millet was substantially higher than that of black millet (24.66 ± 0.05), indicating greater lightness. The a* value, which denotes redness, was higher in black millet (13.00 ± 0.05) than in white millet (7.70 ± 0.05), while the b* value (yellowness) was significantly more intense in white millet (28.35 ± 0.05) compared to black millet (10.35 ± 0.05). Chroma (C*) and hue angle (H°) values were also significantly greater in white millet (29.38 ± 0.05 and 74.81 ± 0.05, respectively), indicating more vibrant coloration in the yellow spectrum. In contrast, the darker and duller color of black finger millet reflected lower pigment brightness and saturation.

Supporting literature further illustrates these findings they are Panwar et al. (2024) [29] reported a thousand-grain weight of 2.56 g for the VL-380 finger millet cultivar, while Ramappa et al. (2011) [30] documented higher values of 3.39 g and 3.27 g for GPU-28 and L-15 varieties, respectively. This parameter is often used as an indirect measure of grain hardness, with harder grains offering advantages for industrial processing due to reduced breakage and suitability for starch production—attributes influenced by varietal genetics.

Hiremath et al. (2019) [31] found raw finger millet varieties to have volumes ranging from 3.3 to 3.7 ml, consistent with the present study. Similarly, Shashi B.K. (2005) [32] reported thousand-seed volumes of 2.6 to 3.6 ml across eight varieties. Hydration capacity, which indicates a material's water absorption under low-speed centrifugation, ranged from 0.82 to 1.45 g/100 g in various raw millet samples, as noted by Vidhyavati (2001) [33]. For instance, Sravanthi et al. (2021) [34] recorded a hydration capacity of 1.03 g/100 g in PRSW-43 white millet. Reddy et al. (2019) [35] observed a hydration capacity of 0.45 ± 0.12 g/1000 kernels, a hydration index of 15.23 ± 0.40, a swelling capacity of 4.5 ± 0.43 ml/1000 kernels, and a swelling index of 12 ± 0.89, values aligning with the present findings.

Color is an important quality determinant in food processing, influencing consumer preference (Pathare et al., 2013) [36]. Ramashia et al. (2018) [37] reported color values for grain samples, with L* values ranging from 19.23 ± 0.42 in black cultivars to 52.97 ± 1.76 in milky cream types. Other studies reported L* values between 68.47 ± 0.85 and 74.00 ± 0.62 for cream-colored grains, significantly higher than those of brown and black types. Siwela et al. (2007) [38] similarly found L* values of 45.9 ± 0.9 to 68.4 ± 0.6. The positive a* and b* coordinates reflect the presence of red and yellow pigments, with significant variability across samples. Chroma (C*) values, representing color intensity, ranged from 10.1 ± 3.99 to 29.1 ± 2.03 in grains and 13.4 ± 0.20 to 7.97 ± 0.23 in flours. Higher chroma and hue angle (H°) values, typically observed in milky cream varieties, indicate more desirable color attributes, essential for consumer appeal.

The hue angle ranged from 35.73° ± 1.06 (black cultivars) to 68.63° ± 0.06 (milky cream cultivars) in grain, and from 62.13° ± 0.98 to 77.3° ± 0.36 in flours. Higher hue angles correlate with yellowish tones, preferred in many food products. Lastly, grain physical traits like size and shape play a pivotal role in post-harvest handling, especially during cleaning and threshing. According to Brennan et al. (1981) [39], these characteristics influence the design and effectiveness of screening equipment used to separate grains from foreign matter.

In conclusion, white finger millet demonstrates notable functional and physical advantages, particularly in terms of hydration and swelling characteristics and colour appeal. These traits enhance its potential for value addition and industrial processing.

Table 2: Physical and functional properties of white finger millet and black finger millet

Physical and Functional properties	Black finger millet	White finger millet	t value
Thousand grain weight(g)	2.4 ± 0.1	2.86 ± 0.115	3.88 (NS)
Seed volume (ml)	2.9 ± 0.1	3.9 ± 0.1	8.66 (NS)
Hydration capacity (g/100 seeds)	0.82 ± 0.05	1.41 ± 0.01	17.76*
Hydration Index	13.91 ±0.80	17.11 ± 0.98	3.21 (NS)
Swelling Capacity (ml/100 seeds)	0.33 ± 0.05	0.50 ± 0.05	50*
Swelling Index	11.62 ± 0.57	17. 57 ± 0.81	70.72**
Bulk Density(Kg/ m^3)	0.82 ± 0.06	0.74 ± 0.04	1.48 (NS)
Color values			
L*	24.66 ± 0.05	57.68 ± 0.05	940**
a*	13.00 ± 0.05	7.70 ± 0.05	917**
b*	10.35 ± 0.05	28.35 ± 0.05	3117**
C*	16.61 ± 0.05	29.38 ± 0.05	1916**
Hue angle(h)	38.41 ± 0.05	74.81 ±0.05	5459**

Each value is the average of three determinants
*S- Significant NS-Non Significant * Significant at 5 % ** Significant at 1%*

3.3 Effect of pretretments on the proximate composition of white finger millet

Table 3 presents the impact of various pretreatments on the proximate composition of white finger millet. In its raw (control) state, the grain contained 9.77% moisture, 10.48% protein, 1.59% fat, 3.11% ash, 3.82% fiber, and 71.21% carbohydrates per 100 g. Roasting reduced the moisture and protein content to 9.31% and 8.45%, respectively, while increasing ash to 3.66% and carbohydrates to 73.01%. Popping further decreased moisture to 8.51% and slightly increased protein to 10.59%, with minimal changes observed in fat (1.35%) and fiber (3.77%). Malting significantly enhanced protein (11.25%) and fiber (5.15%) content, accompanied by a reduction in fat (1.15%) and carbohydrates (70.42%). Combination treatments involving malt with TS1, TS2, and TS3 produced variable effects across all parameters, reflecting the flexibility of such interventions in tailoring the nutritional composition of finger millet to specific dietary and processing needs.

Comparable findings were reported by Shobha et al. (2023) [40], who observed that white finger millet contained 10.20 ± 0.10% moisture, 2.69 ± 0.01% ash, 4.20 ± 0.10% fat, 8.90 ± 0.10% protein, and 3.76 ± 0.10% crude fiber, with carbohydrates comprising 70.95 ± 0.55% and contributing to an energy value of 357.2 ± 10.56 kcal. Navyashree et al. (2022) [41] highlighted significant ($p < 0.05$) differences in the proximate composition of native flour (Nf), roasted flour (Rf), and germinated flour (Gf). Moisture content increased in Gf due to water uptake during soaking (Abioye et al., 2018) [42], while it decreased in Rf due to water loss during roasting (Kumar et al., 2019) [43]. Protein content was elevated in Gf, likely due to the reduction in starch and synthesis of amino acids during germination. Rf exhibited lower protein content due to thermal degradation and the volatilization of nitrogenous compounds. Crude fiber was highest in Gf, attributed to enhanced cell wall synthesis, while fat content declined in both Gf and Rf, either due to fat utilization during germination or complex formation during roasting (Yousaf et al., 2021) [44]. Carbohydrate content ranged between 74.64% and 77.79%, increasing in Rf and decreasing in Gf due to sugar metabolism during sprouting. Ash content increased significantly in Rf, possibly due to phytic acid degradation during heating, improving mineral bioavailability.

Previous studies have documented similar trends. According to Chilkawar et al. (2010) [45], Bhosale et al. (2020) [46] and Hiremath & Geetha (2019) [47], malting enhances protein content (7.39–13.98%) and fiber (2.48–7.02%) due to enzymatic hydrolysis of storage compounds. Fat content (0.83–3.70%) typically decreases slightly due to lipolytic activity, while ash content (1.94–4.90%) increases due to improved mineral bioavailability following phytate reduction. Total carbohydrate content (64.96–76.84%) tends to decline slightly during malting but becomes more digestible due to increased enzymatic activity and the accumulation of reducing sugars.

Chauhan and Saroj (1986) [48] and Malleshi et al. (1986) [49] also reported significant compositional changes post-malting and thermal steaming. Moisture content decreased (10–12% to 8–10%) due to drying, while protein increased (7–8% to 9–11%) from enhanced digestibility of hydrolyzed proteins. Fat content marginally declined (1.5–2.5% to 1.2–2.0%), likely due to lipolytic activity. Ash content increased slightly (2.2–2.5% to 2.5–3.0%) as phytate degradation improved mineral accessibility. Fiber content showed a slight reduction (3.6–4.0% to 3.0–3.5%) due to fiber softening. Carbohydrate content remained relatively stable (72–76%) but showed improved digestibility due to enzymatic breakdown and starch gelatinization, enhancing the flour's functional and processing properties(Nirmala & Muralikrishna, 2003) [50].

The results of various pretreatments on the proximate composition of white finger millet demonstrate significant changes in its nutritional profile. Roasting, popping, and malting were found to alter the moisture, protein, fiber, fat, and carbohydrate contents in distinct ways, making the millet suitable for different processing and dietary needs. Specifically, malting led to a substantial increase in protein and fiber, which could enhance the nutritional value of the millet for health-focused applications. Overall, these pretreatments offer a promising means to modify the functional properties of finger millet, increasing its versatility in food processing and product development.

Table 3: Effect of pretretments on the proximate composition of white finger millet

Pre-treatments	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Fibre (%)	Carbohydrates (%)
Raw (Control)	9.77± 0.04	10.48±0.015	1.59±0.05	3.11±0.08	3.82± 0.02	71.21± 0.18
Roasting	9.31± 0.01	8.45 ±0.04	1.43±0.02	3.66±0.01	4.12 ± 0.05	73.01 ± 0.05
Popping	8.51± 0.03	10.59 ± 0.08	1.35±0.03	3.24±0.01	3.77 ± 0.01	72.85 ± 0.60
Malting	9.03± 0.05	11.25 ± 0.28	1.15±0.03	2.98±0.05	5.15 ± 0.04	70.42 ± 0.35
Malt + TS1	10.52±0.02	8.55 ± 0.1	1.14±0.04	2.97±0.02	4.14 ± 0.03	72.66 ± 0.21
Malt + TS2	10.64±0.03	8.14 ± 0.05	1.15±0.03	2.96±0.02	4.12 ±0.02	72.98 ± 0.12
Malt + TS3	10.73±0.02	8.05 ± 0.05	1.11±0.01	2.95±0.01	4.03 ± 0.03	73.11 ± 0.12
F value	1781.13	373.456	78.198	182.037	922.327	39.26
SE(m)	0.021	0.027	0.021	0.019	0.015	0.17
CD at 5%	0.064	0.215	0.064	0.059	0.046	0.52

Each value is the average of three determinants
TS1- Thermal steaming 1, TS2- Thermal steaming 2, TS3- Thermal steaming 3

3.4 Effect of pre treatments on the mineral content of white finger millet

Table 4 presents the mineral composition of white finger millet after different pretreatments. In its raw form, the millet contains 301.06 mg/100g of calcium, 1.57 mg/100g of iron, 2.21 mg/100g of zinc, 142.36 mg/100g of magnesium, 225.33 mg/100g of phosphorus, and 383.43 mg/100g of potassium. Roasting slightly reduces calcium content to 298.23 mg/100g, while iron content increases to 5.31 mg/100g, with minimal changes in zinc, magnesium, phosphorus, and potassium levels. Popping results in similar trends, with calcium at 299.46 mg/100g, iron at 4.92 mg/100g, and zinc at 2.05 mg/100g, while magnesium, phosphorus, and potassium remain relatively unchanged compared to the raw form. Malting leads to a significant increase in calcium (323.66 mg/100g) and exhibits varied effects on the levels of iron, zinc, magnesium, phosphorus, and potassium, ranging from 3.67 mg/100g to 390.3 mg/100g depending on the specific treatment. Combination treatments, such as malt with TS1, TS2, and TS3, exhibit consistent mineral profiles with minor variations across calcium, iron, zinc, magnesium, phosphorus, and potassium, indicating the broad influence of pretreatments on the mineral composition of white finger millet.

In line with previous studies, Shobha et al. (2023) [40] reported that white finger millet is a rich source of minerals, with 343.20 ± 0.80 mg of calcium, 283.73 ± 0.64 mg of phosphorus, and 3.80 ± 0.12 mg of iron per 100 grams. Similarly, Navyashree et al. (2022) [41] observed that raw, roasted, and germinated finger millet exhibited variations in mineral content, with calcium ranging from 261.49–308.04 mg/100 g, magnesium from 140.50–143.80 mg/100 g, phosphorus from 223.2–226.10 mg/100 g, and iron from 1.58–5.28 mg/100 g. These findings are consistent with earlier reports by Nakarani et al. (2021) and Chauhan (2018) [51], which highlighted higher levels of calcium, magnesium, and iron in germinated finger millet compared to raw millet.

Thermal steaming has also been found to significantly enhance the mineral content and bioavailability of finger millet, particularly for calcium and iron. Raw finger millet typically contains between 350-450 mg of calcium per 100 g, and after steaming, calcium retention remains high at 350-420 mg/100 g (Chauhan & Saroj, 1986) [48]. The iron content, which ranges from 3.0-4.0 mg per 100 g in raw millet, shows a slight increase after steaming (3.5-4.2 mg/100 g), likely due to the reduction of phytic acid, which enhances iron bioavailability (Malleshi et al., 1986). Magnesium content remains relatively stable during steaming, with minimal loss (120-145 mg/100 g), while phosphorus levels are preserved (270-290 mg/100 g) after steaming (Bhosale et al., 2020) [46]. Zinc levels are also retained during thermal treatment, ranging from 1.0-2.3 mg/100 g. These findings highlight that thermal steaming not only preserves but may also improve the bioavailability of key minerals like calcium, iron, and zinc, thereby enhancing the nutritional value of finger millet for diverse applications.

The pretreatment processes, including roasting, popping, malting, and thermal steaming, have a noticeable impact on the mineral composition of white finger millet. While roasting and popping lead to minor variations, malting and steaming notably increase the availability of essential minerals like calcium, iron, and magnesium. These alterations in the mineral content enhance the nutritional value of finger millet, making it more suitable for various food applications. The results suggest that pretreatment processes offer effective means of optimizing the mineral profile of finger millet, contributing to its functional and nutritional benefits.

Table 4: Effect of pre treatments on the mineral content of white finger millet

Pretreatments	Calcium (mg/100g)	Iron (mg/100g)	Zinc (mg/100g)	Magnesium (mg/100g)	Phosphorus (mg/100g)	Potassium (mg/100g)
Raw	301.06±0.40	1.57±0.01	2.21±0.01	142.36±0.32	225.33 ±0.57	383.43±0.40
Roasting	298.23±0.25	5.31±0.01	2.38±0.05	138.53±0.50	222.66 ± 0.57	378.66±0.57
Popping	299.46±0.45	4.92±0.04	2.05±0.04	136.2 ± 0.26	218.83 ± 0.76	375.66± 0.57
Malting	323.66±0.57	3.67±0.04	2.54±0.04	144.4±0.360	224.43 ± 0.40	390.3 ± 0.43
Malt + TS1	323.66±0.57	3.67±0.04	2.54±0.04	144.4±0.360	224.43 ± 0.40	390.3 ± 0.43
Malt + TS2	323.66±0.57	3.67±0.04	2.54±0.04	144.4±0.360	224.43 ± 0.40	389.86± 0.32
Malt + TS3	323.5 ± 0.86	3.66±0.05	2.46±0.18	144.23±0.23	224.35 ± 0.40	388.33± 0.57
F value	1603.42	2427.47	19.01	245.204	53.07	478.45
SE(m)	0.322	0.024	0.044	0.215	0.302	0.277
CD at 5%	0.985	0.074	0.134	0.659	0.926	0.848

Each value is the average of three determinants
Ts1- Thermal steaming 1, TS2- Thermal steaming 2, TS3- Thermal steaming 3

4.5 Effect of pre treatments on anti nutritional factors of white finger millet

Table 5 illustrates the phytate content (mg/100 g) of white finger millet subjected to various pretreatment methods. The raw sample exhibited the highest phytate concentration at 148.66 mg/100 g. Roasting significantly decreased this level to 58.65 mg/100 g, while popping also resulted in a notable reduction to 61.73 mg/100 g. Malting further lowered the phytate content to 52.60 mg/100 g. Additional treatments combining malting with thermal steaming strategies (TS1, TS2, and TS3) led to further reductions, with TS1 and TS2 both showing 50.03 mg/100 g, and TS3 achieving the lowest value of 49.66 mg/100 g. These results confirm that all pretreatments are effective in reducing phytate concentrations, with combined malting and thermal treatments yielding the most substantial reductions. Notably, the tannin content was found to be absent in both raw and all pretreated samples.

Processing methods such as roasting, popping, and malting, and their combinations with thermal steaming have been proven effective in reducing anti-nutritional factors in finger millet, particularly phytates and tannins. According to Bansal and Kaur (2018), raw finger millet typically contains 297 mg/100 g of phytates and 0.82 mg/100 g of tannins. Roasting reduces phytates to 250 mg/100 g and tannins to 0.75 mg/100 g, primarily due to the heat-induced breakdown of these compounds. Popping, which subjects the grain to high temperature for a short duration, further reduces phytate levels to 162 mg/100 g and tannins to 0.50 mg/100 g. Malting, involving controlled soaking, germination, and drying, activates endogenous enzymes that hydrolyze these anti-nutrients, lowering phytates to 163 mg/100 g and tannins to 0.58 mg/100 g.

The most pronounced reduction is observed when malting is combined with thermal steaming, bringing phytate levels down to 150 mg/100 g and tannins to 0.45 mg/100 g. These combined treatments enhance enzymatic activity and thermal degradation, thereby maximizing the reduction of anti-nutritional factors and improving mineral bioavailability and nutritional quality.

The data demonstrate that pretreatment methods such as roasting, popping, and malting, and their combinations with thermal steaming effectively reduce phytate levels in white finger millet, with tannins eliminated. Among these, combined treatments are the most effective. These reductions enhance the grain's nutritional value and support its potential as a more bioavailable and health-promoting food source.

Table 5: Effect of pre treatments on anti nutritional factors of white finger millet

Pre-treatments	Phytates (mg/100g)	Tannins (mg/100g)
Raw	148.66 ±00	0
Roasting	58.65 ± 00	0
Popping	61.73 ± 0.30	0
Malting	52.60 ± 0.52	0
Malt + TS1	50.03 ± 0.05	0
Malt + TS2	50.03 ± 0.05	0
Malt + TS3	49.66 ± 0.57	0
F value	20355.91	0
SE(m)	0.254	0
CD at 5%	0.776	0

Each value is the average of three determinants
TS1- Thermal steaming 1, TS2- Thermal steaming 2, TS3- Thermal steaming 3

4. Conclusion

This study comprehensively evaluated the effect of various pre-treatments on the dimensional, physico-chemical, and nutritional attributes of white finger millet, with black finger millet serving as a control. The results demonstrate that white finger millet possesses superior physical characteristics, including higher geometric and arithmetic mean diameters, surface area, and sphericity. These traits are advantageous for processing and improve the grain's market potential. Pre-treatments significantly enhanced the nutritional composition of the grain. Malting notably increased protein and dietary fiber content, while roasting and thermal steaming improved carbohydrate levels. The functional properties, such as hydration and swelling capacities, were also elevated in treated samples, particularly in white millet, indicating improved cooking qualities and suitability for diverse food applications.

Mineral analysis revealed a substantial retention or increase in calcium, iron, zinc, and magnesium after processing. Among all methods, the combination of malting with thermal steaming (TS3) yielded the highest reduction in anti-nutritional factors, with phytates dropping to 49.66 mg/100g and complete elimination of tannins, thus significantly enhancing mineral bioavailability. The study confirms that white finger millet when subjected to appropriate pre-treatments, emerges as a nutrient-dense, functionally versatile grain. It holds great promise for incorporation into health-based diets and fortified food products aimed at addressing micronutrient deficiencies. These findings also emphasize the importance of simple, low-cost processing techniques in improving the nutritional quality of traditional crops, making them more acceptable and beneficial for consumers, especially in nutritionally vulnerable populations.

5. Future scope of study

- Optimize processing methods for better nutrient retention and large-scale use.
- Study bioavailability of minerals and health effects post-treatment.
- Develop millet-based products for kids, women, and elderly nutrition.
- Use in nutrition programs to reduce malnutrition in communities.

6. Conflict of interest

The authors declare that there are no conflicts of interest related to this study.

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