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Comparative Study of Malted and Unmalted Finger Millet (GIRA-2 Variety): Processing and Engineering Implications

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Abstract

Malting is an important bioprocessing operation that alters the physical structure and nutritional composition of cereal grains, thereby influencing their processability. This study evaluated the effect of malting on the physical, gravimetric, and proximate properties of finger millet (*Eleusine coracana* L.) variety GIRA-2 from a food engineering perspective. Grains were subjected to controlled steeping, germination, and drying to obtain malted samples, while unmalted grains served as controls. Physical properties including grain dimensions, geometric mean diameter, sphericity, surface area, bulk density, true density, and porosity were determined using standard engineering methods. Proximate composition was analysed following AOAC (2019) procedures. All analyses were conducted in triplicate, and statistical differences were evaluated using independent *t*-tests ($p \leq 0.05$). Malting significantly reduced bulk and true densities while increasing porosity, indicating improved hydration and milling behavior. An increase in crude protein and ash content was also observed, reflecting enhanced nutritional quality. The results demonstrate that malting improves both processing characteristics and nutritional attributes of finger millet, supporting its utilization in value-added and functional food applications.

Keywords: GIRA-2 Finger millet, Malted finger millets, Physical properties, Proximate composition, Nutritional improvement

1. Introduction

Finger millet (*Eleusine coracana L.*) is one of the most important minor cereals widely cultivated in India and Africa. It is known for its exceptional resilience under dryland conditions and its high nutritional profile, being rich in calcium, iron, dietary fiber, and polyphenols. The variety GIRA-2 is an improved cultivar known for its yield stability and adaptability.

Malting is a controlled germination process involving steeping, germination, and kilning, which induces biochemical changes in the grain. During malting, complex macromolecules such as starch and proteins are hydrolyzed into simpler forms by enzymatic activity. These modifications not only improve nutrient bioavailability but also influence physical properties such as density, porosity, and grain hardness (Suresh *et al.,* 2018).

Proximate composition is essential to evaluate the overall nutritional quality of malted products. Malting generally decreases crude fat and moisture contents while increasing crude protein and ash due to metabolic activation (Kavitha & Tharanathan, 2016). Such transformations enhance the digestibility and functionality of cereal-based foods.

The variety CFMV 2 (GIRA) (often referred to as GIRA-2) is a nationally identified variety developed from local germplasm; it is recommended in several Indian states and noted for high grain and fodder yield and improved nutrition. Characterizing the physical and proximate properties of GIRA-2, especially before and after malting, supports its use in processed foods and fortification applications. Harshal E *et al*., (2022)

2. Materials and Methods

2.1 Sample Collection

Finger millet (*Eleusine coracana L.*) variety GIRA-2 was procured from the Millet Research Station, Gujarat, India. Grains were cleaned manually to remove foreign matter and broken kernels.

2.2 Malting Process

Malting of Finger Millet

The malting procedure for Finger millet has been performed following established methods reported in earlier studies, with appropriate modifications to optimize sprouting and enzyme development.

Soaking:

Cleaned millet grains were steeped in potable water at a grain-to-water ratio of approximately 1:3 (w/v). The steeping was conducted at 25–30°C for about 8–12 hours to achieve adequate moisture uptake required for uniform germination, as supported by recent malting protocols (Singh *et al.,* 2020).

Germination:

After steeping, the hydrated grains were spread evenly on germination trays and incubated at 25°C under controlled aeration and humidity. Germination was allowed to proceed for 48–72 hours, during which sprout growth and hydrolytic enzyme activity are maximized (Chung *et al.,* 2019; Adewale & Adebayo, 2022).

Kilning/Drying:

The germinated grains were dried in a tray dryer at 50–60°C for 8–12 hours to halt enzymatic activity and reduce moisture to safe storage levels. Controlled kilning ensures desirable flavour, enzyme preservation, and extended shelf life (Patil *et al.,* 2021; Sharma & Joshi, 2023).

Milling:

Once dried, the malted grains were milled using a hammer mill fitted with a 250-µm sieve to obtain fine malt flour suitable for blending and product formulation. The powdered malt was packed in airtight containers to prevent moisture uptake and quality deterioration (Balasubramanian *et al.,* 2014; Raghavendra *et al.,* 2022).

2.3 Determination of Moisture Content

Moisture content (%) was measured using a hot-air oven at 105 °C until constant weight (AOAC, 2005). Moisture content of the seed samples was estimated using a thermostatically controlled hot air oven following standard procedures. The oven temperature was maintained at **105 ± 2°C**, ensuring uniform drying conditions. Approximately **25–30 g** of grains from each variety were weighed into clean, non-corrosive metallic containers and dried in the oven for **24 hours**, as recommended in classical methodologies. After drying, the samples were transferred to a desiccator, allowed to cool to room temperature, and reweighed. The samples were again placed in the oven for an additional **2 hours** of drying, cooled, and weighed. This cycle of drying and weighing was repeated until a **constant weight** was obtained, indicating the removal of moisture.

The moisture content on a **wet basis** was calculated using the following equation:

$$\text{Moisture Content (wb, \%)} = \frac{100 \times (W_1 - W_2)}{W_1}$$

where:

- W_1= Initial weight of the sample (g)
- W_2= Final constant weight of the sample (g)

2.4 Physical Properties of millets

2.4.1 **Size and Geometric Properties:** The size parameters measured included Length (L), Width (W) and Thickness (T) of randomly selected grains (n=50) were measured using a digital micrometre with and digital Vernier caliper (accuracy 0.01 mm) (Mohsenin, 1986). Calculate geometric mean diameter (Dg) by using formula is,

$$\mathbf{Dg}=(\mathrm{L} \times \mathrm{W} \times \mathrm{T})^{1/3}$$

2.4.2 **Sphericity (Φ)**: Sphericity (%) is explained as the ratio of the surface area of a sphere having the same volume as the grain to the surface area of the grain and was calculated using following equation.

$$\mathbf{\Phi} = \frac{\mathrm{Dg}}{\mathrm{L}}$$

2.4.3 **1000-Grain Weight**: One thousand seeds were selected randomly from the seed sample and weighed using an electronic balance (capacity 2000 g, accuracy 0.1 g). Three samples of 1000 grains were weighed and the mean weight was calculated. (accuracy ±0.001 g) (Singh and Goswami,1996).

2.5 Gravimetric Properties: (Mohsenin, 1986)

The Gravimetric Properties of grains, Bulk density (ρb) was determined by using a 500 mL graduated cylinder filled without tapping and **True density (ρt)** was measured by using the toluene displacement method.

2.5.1 **Bulk Density (ρb)**: Bulk density Bulk density (kg/m3) is described as the ratio of the mass of the sample to its total volume. It was determined by filling a 500 mL cylinder with grains. Bulk density (kg/ m^3) was calculated as a ratio between the sample weight and the volume of the cylinder using below equation:

$$\mathbf{\rho b}= \frac{\textbf{Mass of Grains}}{\textbf{Volume of cylinder}}$$

2.5.2 True Density (ρt): Use Toluene displacement method because toluene does not absorb moisture. The true density (kg/m^3) was determined by the toluene displacement method using a top loading balance. A total of 100 g of grains were immersed in graduated beaker containing toluene. The amount of toluene displacement was recorded using below equation

$$\rho t = \frac{\text{Mass of grains}}{\text{Volume of toluene displayed or True Volume}}$$

2.5.3 Porosity (ε): Porosity (%) is defined as the fraction of the space in bulk grain that is not occupied by the grain. It was calculated using below equation from the true density and bulk density using method.

$$\text{Porosity } (\varepsilon) = \left(1 - \frac{\rho b}{\rho t}\right)$$

All parameters were measured in triplicate using standard methods described by Mohsenin (1986).

2.6 Proximate Analysis

The proximate composition of both malted and unmalted millet samples was determined according to **AOAC (2019)** methods which is described below:

2.6.1 Determination of Crude Protein (Kjeldahl Method): The organic nitrogen in the sample is converted to ammonium sulfate during digestion. Ammonia released during distillation is titrated, and total protein is calculated using a nitrogen conversion factor.

Procedure:

1. One gram of dried sample was transferred to a Kjeldahl digestion flask.
2. A catalyst mixture (K_2SO_4 + $CuSO_4$) and concentrated **H_2SO_4** were added.
3. The flask was heated until a clear, colorless digest was obtained.
4. The digest was cooled, diluted with distilled water, and transferred to a distillation unit.
5. **40% NaOH** was added to render the solution alkaline, releasing ammonia.
6. Ammonia was distilled into a boric acid indicator solution.
7. The distillate was titrated using standardized **0.1 N HCl** until the endpoint.
8. **Total nitrogen (%)** was calculated and converted to crude protein using:

$$\text{Crude Protein (\%)} = \text{Nitrogen (\%)} \times 6.25$$

2.6.2. Determination of Crude Fat (Soxhlet Extraction): Lipids are extracted from the sample using a non-polar solvent under reflux conditions.

Procedure:

1. Two grams of dried sample were placed in a cellulose extraction thimble.
2. The thimble was loaded into a Soxhlet apparatus and extracted with **petroleum ether (boiling range 40–60°C)** for **6–8 hours**.
3. After extraction, the solvent was evaporated using a water bath.
4. The remaining residue (fat) was dried in an oven at 105°C to constant weight.
5. Crude fat content was calculated as:

$$\text{Crude Fat (\%)} = \frac{\text{Weight of extracted fat}}{\text{Weight of sample}} \times 100$$

2.6.3. Determination of Total Ash: Ashing removes organic matter by incineration, leaving only inorganic mineral components.

Procedure:

1. About 2 g of sample was placed in a pre-ashed, pre-weighed crucible.
2. The sample was charred gently over a hot plate to prevent spattering.
3. The crucible was then placed in a **muffle furnace at 550 ± 10°C** for **4–6 hours** until light gray ash was obtained.
4. The crucible was cooled in a desiccator and weighed.
5. Ash content was expressed as:

$$\text{Total Ash (\%)} = \frac{W_{\text{ash}}}{W_{\text{sample}}} \times 100$$

2.6.4. Determination of Crude Fiber: The sample undergoes sequential digestion with dilute acid and alkaline solutions to remove non-fibrous materials. The remaining residue is weighed after ignition to determine crude fiber.

Procedure:

1. Two grams of defatted sample were digested with **1.25% H_2SO_4** by boiling for 30 minutes.
2. The mixture was filtered and washed with hot distilled water.
3. The residue was boiled again in **1.25% NaOH** solution for another 30 minutes.
4. After filtration, the residue was washed, dried at 105°C, and weighed.
5. The dried residue was then ignited in a muffle furnace at **550°C** to remove all organic matter.
6. Crude fiber (%) was calculated as:

$$\text{Crude Fiber (\%)} = \frac{W_{\text{residue before ashing}} - W_{\text{ash}}}{W_{\text{sample}}} \times 100$$

2.7 Statistical Analysis: The analyses were performed in triplicate and computed as mean values and standard deviations. The Independent t-tests (two-sample) were used to assess significant differences between malted and unmalted samples at **$p \leq 0.05$**. Statistical analysis was performed using SPSS software version 25.0.

3. Results and Discussion

3.1 Physical Properties

Malting caused significant changes in most physical parameters of finger millet grains. The mean ± SD values and p-values are presented in **Table 1**.

Table 1. Physical Properties of Malted and Unmalted Finger Millet (GIRA-2)

Parameter	Unmalted (Mean ± SD)	Malted (Mean ± SD)	p-value
Moisture %	11.10 ± 0.10	6.83 ± 0.03	0.0002

1000-grain wt g	2.80± 0.03	2.63 ± 0.02	0.0001
Length mm	2.21 ± 0.01	1.72 ± 0.01	0.0001
Width mm	1.73 ± 0.00	1.41 ± 0.00	0.0001
Thickness mm	1.62 ± 0.01	1.12 ± 0.00	0.0001
Sphericity	0.83 ± 0.00	0.80 ± 0.00	0.0001
Surface Area mm²	10.52 ± 0.00	6.07 ± 0.00	0.0001
Size mm	1.83 ± 0.00	1.39 ± 0.00	0.0001
Bulk Density kg/m³	754.23 ± 0.80	720.67 ± 0.76	0.0001
True Density kg/m³	1311.33 ± 0.35	1295.77 ± 1.85	0.0003
Porosity %	43.00 ± 0.00	45.00 ± 0.00	0.0001
Viscosity Cp	1641.3±0.00	862.8±0.00	0.0001

Malting reduced grain dimensions, density, and size due to moisture absorption and enzymatic breakdown of endosperm components during germination. This is consistent with findings reported by Adebowale *et al.,* (2011), who observed decreased density and hardness after malting of cereals. Increased porosity in malted grains improves their hydration and milling characteristics, beneficial for processing. Similar result found for physical properties of unmalted finger millet by Panwar (2024) and for malted finger millet by Joseph (2019).

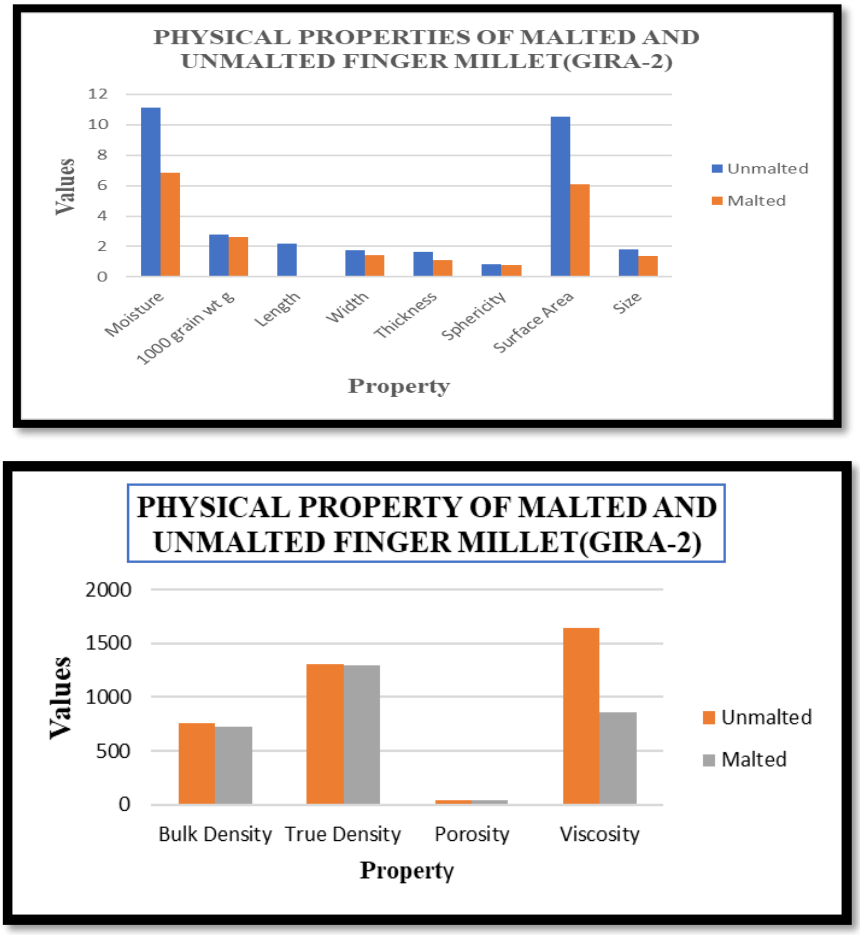

Fig-1.: Comparative bar graph showing the physical properties of malted and unmalted finger millet (GIRA-2)

3.2 Proximate Composition

The proximate composition of malted and unmalted finger millet is summarized in **Table 2**.

Table 2. Proximate Composition of Malted and Unmalted Finger Millet (GIRA-2)

Parameter	Unmalted (Mean ± SD)	Malted (Mean ± SD)	p-value
Moisture	0.109 ± 0.0002	0.068 ± 0.0001	0.0001
Crude Protein	0.073 ± 0.0001	0.086 ± 0.0001	0.0001
Crude Fat	0.0166 ± 0.0001	0.0156 ± 0.0001	0.0012
Total Ash	0.0201 ± 0.0000	0.0213 ± 0.0000	0.0021
Crude Fiber	0.0177 ± 0.0000	0.0160 ± 0.0000	0.0015

A noticeable increase in protein and ash content was observed after malting, which may be attributed to enzymatic hydrolysis and concentration effects from moisture loss. Reduction in fat and fiber content is consistent with earlier studies, suggesting lipid oxidation and breakdown of cell Similar result found for proximate analysis of unmalted finger millet by Panwar(2024) and for malted finger millet by Joseph O Owheruo (2019.) wall components during germination (Abd El-Hady & Habiba, 2003).

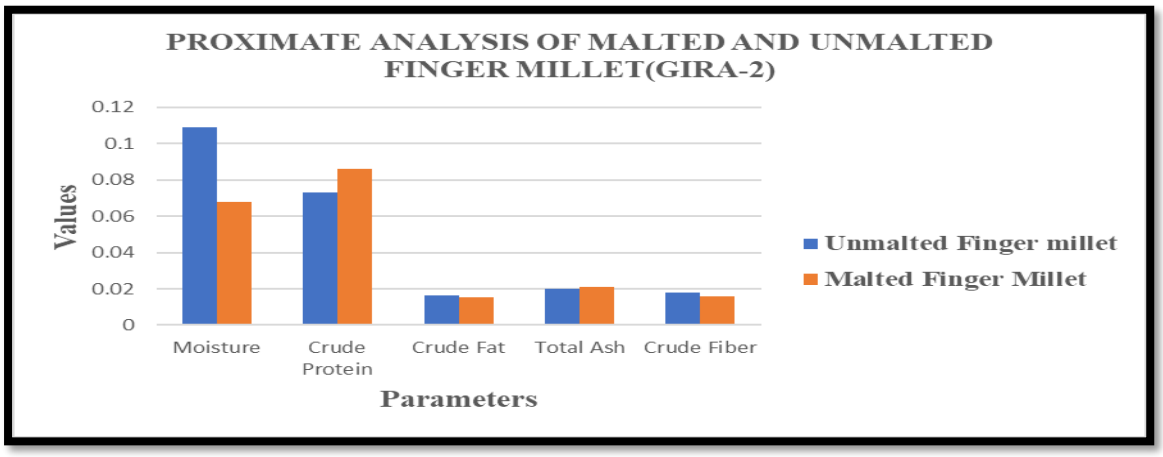

Fig-2.: Comparative bar graph showing the proximate composition of malted and unmalted finger millet (GIRA-2)

Malting improves nutritional quality by enhancing protein digestibility, bioavailability of minerals, and lowering antinutritional factors such as tannins and phytates (Nirmala *et al.,* 2000). These results support the utilization of malted finger millet for fortified and infant food formulations.

4. Conclusion

The present study demonstrates that malting induces significant modifications in the physical and proximate characteristics of finger millet (GIRA-2), thereby influencing its engineering and processing behavior. Malted grains exhibited reduced bulk and true densities, grain size, and moisture content, accompanied by increased porosity and crude protein levels. These structural and compositional changes facilitate improved hydration, reduced viscosity, enhanced milling efficiency, and better nutrient availability. From a food engineering perspective, the observed improvements contribute to superior processability and functional performance of the

malted flour. Consequently, malting emerges as an effective pre-processing strategy for enhancing the quality, nutritional value, and industrial applicability of finger millet, particularly in the development of functional foods, malt-based formulations, and value-added cereal products.

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