

Effect of Flour Particle Size on the Nutritional, Functional, Rheological and Textural Properties of Ragi Dosa and Ragi Vermicelli

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Abstract

Finger millet (*Eleusine coracana*), commonly known as ragi, is a nutritionally dense, gluten-free cereal valued for its high calcium, dietary fibre, protein, and antioxidant content, and it is increasingly used in convenience and value-added food formulations. This study examined how flour particle size influences the nutritional, physicochemical, functional, rheological, and textural quality of ragi-based dosa and vermicelli. Ragi flour was fractionated by sieve analysis into five size classes (212, 180, and 150 μm fractions retained on their respective sieves, a 95+ μm fraction, and a 95– μm fraction passing the 95 μm sieve), and each fraction was evaluated for proximate composition, water activity, colour, alkaline water absorption and solubility, and batter viscosity before being used to prepare dosa and vermicelli. Coarser fractions (212 and 180 μm) retained more protein, crude fibre, and ash, and produced batters of higher viscosity and alkaline water absorption, whereas finer fractions (95+ and 95– μm) were lighter in colour, lower in water activity, and yielded firmer, more cohesive dosa on texture profile analysis. Sensory evaluation identified the 150 μm fraction as most acceptable for dosa and the 95+ μm fraction as most acceptable for vermicelli. These findings indicate that no single particle size is optimal across every quality attribute; rather, intermediate fractions offer the best compromise between nutrient retention, processing behaviour, texture, and consumer acceptability, providing practical guidance for standardizing ragi flour granulation in the development of value-added millet products.

Keywords: Finger Millet, Ragi, Particle Size, Dosa, Vermicelli, Texture Profile Analysis, Sensory Evaluation, Functional Properties

1. INTRODUCTION

Finger millet (*Eleusine coracana*), locally known as ragi, is among the most nutritionally significant millets, prized for its high calcium content, dietary fibre, protein, essential amino acid profile, mineral content, and antioxidant activity. Its low glycaemic index and gluten-free character have made it increasingly attractive for the development of functional and value-added food products, and rising consumer demand for healthy convenience foods has encouraged its incorporation into traditional preparations such as dosa (a fermented or unfermented savoury pancake) and vermicelli.

The quality of millet-based products depends on several processing variables, among which the particle size of the flour is particularly influential. Particle size affects water absorption, batter viscosity, starch gelatinization behaviour, cooking characteristics, and the final structure and sensory acceptability of the

product. Identifying an appropriate particle size is therefore an essential step in standardizing high-quality, ragi-based value-added foods.

In this study, ragi flour was fractionated into five particle size classes using standard sieve analysis: 212 μm , 180 μm , and 150 μm fractions (each retained on its respective sieve), a 95+ μm fraction retained on the 95 μm sieve, and a 95– μm fraction that passed through it. These fractions were used to prepare ragi dosa and ragi vermicelli, and the influence of particle size on the nutritional, functional, physical, rheological, and textural characteristics of the flour and the finished products was systematically evaluated. Proximate analysis (moisture, ash, crude fibre, and protein) was carried out on the flour fractions, alongside functional properties, namely alkaline water absorption capacity (AWAC) and alkaline water solubility index (AWSI), that describe hydration behaviour. Colour and water activity were measured as indicators of appearance and shelf stability. Batter viscosity was assessed using a Brookfield viscometer, and the texture of the finished dosa and vermicelli was quantified by Texture Profile Analysis (TPA), which yields objective measures of hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, resilience, and fracturability. Finally, sensory evaluation was used to relate these instrumental measurements to consumer acceptability, with the overall aim of identifying the particle size range that best balances nutritional retention, processing performance, and eating quality in ragi-based products.

2. Materials and Methods

2.1 Raw Material and Particle Size Fractionation

Commercial ragi (finger millet) flour was fractionated into different particle size classes using a laboratory sieve shaker fitted with standard test sieves arranged in descending order of aperture size (212, 180, and 150 μm , with a collection pan at the base). Sieves were fitted with bouncing rubber cubes ($20 \times 20 \times 20$ mm; three per sieve) to aid separation. A 100 ± 0.01 g sample was loaded onto the topmost sieve, the stack was clamped, and sieving was carried out for 15 minutes. The fractions retained on each sieve were collected with a soft brush and weighed, and recovery was verified against the initial 100 g charge (acceptable deviation ≤ 1 g). This yielded five fractions, namely 212+, 180+, 150+, 95+, and 95– μm , that were used throughout the study (Figure 1).

Figure 1. Laboratory Sieve Shaker Used for Particle Size Fractionation of Ragi Flour



2.2 Proximate Analysis

Moisture content was determined by drying 10 g of each flour fraction in a hot-air oven at 130°C for 2 hours, cooling in a desiccator, and calculating weight loss as a percentage of the initial sample weight. Crude fibre was estimated by sequential acid-alkali digestion (1.25% sulphuric acid and 1.25% sodium hydroxide at 80°C) using a fibre extraction unit, followed by drying (130°C, 3 h) and ashing (400°C, 1 h) of the residue, with fibre content calculated from the weight loss on ignition. Crude protein was determined by the Kjeldahl method: samples were digested with concentrated sulphuric acid in the presence of potassium sulphate and copper sulphate catalysts, distilled following alkalisation with sodium hydroxide, and the liberated ammonia was trapped in boric acid and titrated against standardized hydrochloric acid; nitrogen content was converted to crude protein using a factor of 6.25. Ash content was determined by incinerating 5 g samples in a muffle furnace at 600°C for 6 hours and expressing the residual inorganic matter as a percentage of the sample weight.

2.3 Physical Properties

Water activity (a_w) was measured using a calibrated water activity meter (calibrated against 0.760 and 0.500 saturated salt standards), with samples equilibrated in the measurement chamber until a stable reading was obtained. Colour was measured using a tristimulus colourimeter, calibrated against white and black reference tiles, to obtain CIELAB lightness (L^*), redness/greenness (a^*), and yellowness/blueness (b^*) coordinates, from which chroma (C^*) and hue angle (h°) were derived; multiple readings were taken per sample to account for surface heterogeneity.

2.4 Functional Properties: Alkaline Water Absorption and Solubility

Alkaline water absorption capacity (AWAC) and alkaline water solubility index (AWSI) were determined to characterise the hydration behaviour of each flour fraction. A weighed sample (2.5 g) was suspended in a fixed volume of water in a tared centrifuge tube, agitated intermittently for 30 minutes, and centrifuged (3000 rpm, 15 min). The sediment was weighed to give AWAC, while the supernatant was dried at 105°C to constant weight to determine the dissolved solids used to calculate AWSI, both expressed as a percentage of the dry sample weight.

2.5 Batter Viscosity

The viscosity of ragi dosa batter prepared from each flour fraction was measured using a Brookfield (DV-E) viscometer fitted with an RV6 spindle operated at 20 rpm for 30 seconds, ensuring the torque reading remained within the 10-90% range; readings were taken once the torque and centipoise values had stabilised, and the instrument was periodically checked against standard viscosity oils.

2.6 Preparation of Ragi Dosa

Ragi dosa premix was prepared by combining ragi flour (100 g) from each particle size fraction with a rice flour blend (100 g; a 1:1 ratio) composed of urad dhal (48 g), idiyappam flour (44 g), sodium bicarbonate (2.2 g), malic acid (1.2 g), fenugreek powder (1.6 g), and salt (3 g). Water was added to form a smooth, pourable batter, which was poured onto a preheated dosa tawa (180-200°C), spread into a thin circular shape, and cooked for 2-3 minutes on the first side and 1-2 minutes after turning, before being evaluated for quality (Figure 2).

Figure 2. Ragi Dosa Prepared from a Finer Flour Fraction, Showing Product Appearance and Structure



2.7 Preparation of Ragi Vermicelli

For vermicelli, ragi flour and refined wheat flour (maida) were combined in an 11:9 ratio, with 1% salt, and water was added gradually while kneading until a smooth, cohesive dough was obtained. The dough was extruded through a hand extruder fitted with a vermicelli die and steamed for 10-15 minutes at 100°C prior to quality evaluation (Figure 3).

Figure 3. Ragi Vermicelli Strands Prepared from the Flour Fractions



2.8 Texture Profile Analysis

The textural properties of ragi dosa and ragi vermicelli were measured using a texture analyzer. For dosa, a P/32R cylindrical probe was used to perform a two-bite compression cycle, from which hardness, fracturability, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience were computed automatically from the recorded force-time curve. For vermicelli, a triple ring cutting system was used: samples (~60 g) were placed centrally in a 95 mm test vessel and sheared by concentric cutting rings (contact force 200 g; return distance 100 mm; return speed 10 mm/s), with maximum cutting force (firmness) and the area under the force-time curve (work of shear) recorded for each sample.

2.9 Sensory Evaluation

Dosa and vermicelli prepared from each particle size fraction were evaluated by a semi-trained sensory panel for appearance, colour, taste, texture, and overall acceptability using a 9-point hedonic scale, and mean scores were compared across fractions.

3. Results and Discussion

3.1 Particle Size Distribution

Sieve fractionation showed that the majority of the ragi flour passed through the 95 μm sieve, with progressively less material retained as sieve aperture increased, confirming that the parent flour was predominantly fine, with only small proportions retained on the intermediate (118-150 μm) sieves. This distribution meant that the finer classes (95+ and 95– μm) represented the bulk of the flour, while the coarser classes (212 and 180 μm) were comparatively minor fractions enriched in larger particles.

3.2 Proximate Composition

Moisture content varied only marginally across fractions (Table 1), ranging from 11.02% (95+ μm) to 11.48% (212+ μm), indicating that particle size had little bearing on the equilibrium moisture of the flour.

Table 1. Moisture Content of Ragi Flour Fractions

Sieve Size (μm)	Moisture Content (%)
212+	11.48
180+	11.03
150+	11.33
95+	11.02
95–	11.17

Crude fibre, protein, and ash content, in contrast, all declined as particle size decreased (Tables 2-4). Crude fibre ranged from 4.51% (212+ μm) to 1.08% (95– μm), with the 180+ μm fraction showing the single highest value (7.35%); protein fell from 11.37% (212+ μm) to 3.99% (95– μm); and ash decreased from a maximum of 3.93% (180+ μm) to 1.19% (95– μm). This pattern is consistent with the tendency of bran- and germ-associated tissue, which is comparatively rich in protein, fibre, and minerals, to resist size reduction and concentrate in the coarser sieve fractions, while the starchy endosperm, which is lower in these constituents, is preferentially reduced to finer particles during milling.

Table 2. Crude Fibre Content of Ragi Flour Fractions

Sieve Size (μm)	Crude Fibre (%)
212+	4.51
180+	7.35
150+	4.13
95+	3.04
95–	1.08

Table 3. Crude Protein Content of Ragi Flour Fractions

Sieve Size (μm)	Protein Content (%)
212+	11.37
180+	10.20
150+	9.19
95+	5.97
95–	3.99

Table 4. Ash Content of Ragi Flour Fractions

Sieve Size (μm)	Ash Content (%)
212+	3.79
180+	3.93
150+	3.70
95+	1.94
95–	1.19

3.3 Physical Properties

Water activity decreased slightly with decreasing particle size, from 0.475 (212+ μm) to 0.422 (95– μm) (Table 5), suggesting that the finer fractions may confer a marginal shelf-stability advantage, although the overall range was narrow.

Table 5. Water Activity of Ragi Flour Fractions

Sieve Size (μm)	Water Activity
212+	0.475
180+	0.448
150+	0.445
95+	0.444
95–	0.422

Colour measurements (Table 6) showed a clear lightening trend with decreasing particle size: lightness (L^*) rose from 50.31 (212+ μm) to 81.71 (95– μm), while redness (a^*) fell from 5.67 to 3.21 over the same range, and yellowness (b^*), chroma (C^*), and hue angle (h°) all increased. This is consistent with the finer fractions being depleted of the darker bran and germ material that concentrates in the coarser fractions, leaving a lighter, more starch-rich flour.

Table 6. CIELAB Colour Values of Ragi Flour Fractions

Sieve Size (μm)	L^*	a^*	b^*	C^*	h°
212+	50.31	5.67	6.20	8.40	47.54
180+	51.21	5.96	6.36	8.72	46.89
150+	58.77	5.16	6.80	8.54	52.82
95+	71.29	4.29	8.67	9.53	63.67
95–	81.71	3.21	9.30	9.83	70.92

3.4 Functional Properties

Alkaline water absorption capacity (AWAC) was highest in the intermediate 150+ μm fraction (279.80%) and lowest in the 95– μm fraction (235.15%) (Table 7), while alkaline water solubility index (AWSI) peaked in the 180+ μm fraction (6.03%) and was lowest in the 95– μm fraction (2.70%) (Table 8). Together these results indicate that the coarser and intermediate fractions hydrate and swell more readily and release more soluble solids than the finer fractions, likely reflecting differences in starch damage and surface area exposed during milling.

Table 7. Alkaline Water Absorption Capacity (AWAC) of Ragi Flour Fractions

Sieve Size (μm)	AWAC (%)
212+	270.90
180+	277.38
150+	279.80
95+	246.08
95–	235.15

Table 8. Alkaline Water Solubility Index (AWSI) of Ragi Flour Fractions

Sieve Size (μm)	AWSI (%)
212+	4.89
180+	6.03
150+	5.71
95+	4.20
95–	2.70

3.5 Batter Viscosity

Batter viscosity ranged from 1870 cP (95+ μm) to 4530 cP (180+ μm) (Table 9). The coarser fractions produced consistently more viscous batters than the finer fractions, in line with their higher water absorption capacity, and this has direct implications for batter handling, spreadability, and cooking behaviour on the tawa.

Table 9. Viscosity of Ragi Dosa Batter Prepared from Different Flour Fractions

Sieve Size (μm)	Viscosity (cP)
212+	3780
180+	4530
150+	3340
95+	1870
95–	2390

3.6 Water Requirement for Batter and Dough Preparation

The volume of water required to prepare a standard dosa batter (100 g ragi flour + 100 g rice blend) ranged from 390 mL (150+ μm) to 470 mL (180+ μm) (Table 10), broadly tracking the viscosity and water-absorption results above. For vermicelli dough (110 g ragi flour + 90 g maida), water requirement ranged more widely, from 150 mL (150+ μm) to 280 mL (95– μm) (Table 11), the reverse trend to that seen for dosa batter, reflecting the different hydration demands of a kneaded dough compared with a pourable batter.

Table 10. Water Required for Ragi Dosa Batter Preparation

Sieve Size (μm)	Water Required (mL)
212+	410
180+	470
150+	390

Sieve Size (μm)	Water Required (mL)
95+	400
95–	420

Table 11. Water Required for Ragi Vermicelli Dough Preparation

Sieve Size (μm)	Water Required (mL)
212+	220
180+	200
150+	150
95+	170
95–	280

3.7 Texture Profile of Ragi Dosa

Texture profile analysis of the finished dosa (Table 12) showed that the 95– μm fraction produced the firmest and most cohesive product, with the highest hardness (27,547.84), springiness (2.33), cohesiveness (0.82), gumminess (18,243.23), and chewiness (19,661.87), while the 212+ μm fraction showed the highest fracturability (8.30), indicating a more brittle structure. The 150+ μm fraction had the lowest hardness (14,959.03) and fracturability (3.20) of all fractions. Overall, finer flour produced a firmer, more cohesive dosa, while coarser flour resulted in a more brittle product, a pattern consistent with the higher fibre and bran content of the coarser fractions disrupting the continuity of the starch-based matrix.

Table 12. Texture Profile Analysis of Ragi Dosa Prepared from Different Flour Fractions

Sieve Size (μm)	Hardness	Fracturability	Adhesiveness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
212+	24345.39	8.30	–51.68	0.97	0.37	7778.58	8570.59	0.22
180+	23785.04	5.20	1.05	0.91	0.79	39534.18	11521.54	0.56
150+	14959.03	3.20	–1.89	0.71	0.75	11839.40	10484.60	1.40
95+	23447.24	2.58	–50.71	0.99	0.57	14300.72	14511.08	0.29
95–	27547.84	3.54	–70.75	2.33	0.82	18243.23	19661.87	0.61

3.8 Texture Profile of Ragi Vermicelli

For vermicelli (Table 13), the 180+ μm fraction produced the firmest strands, with the highest firmness (1.152 kg) and work of shear (3.48 kg·sec), while the 150+ μm fraction gave the softest product (firmness 0.704 kg; work of shear 1.76 kg·sec). The intermediate-coarse fractions therefore produced firmer vermicelli than either the finest or the coarsest fractions, suggesting that a balance between starch integrity and fibre reinforcement is needed to maximise strand strength.

Table 13. Texture Profile Analysis of Ragi Vermicelli Prepared from Different Flour Fractions

Sieve Size (μm)	Firmness (kg)	Work of Shear (kg·sec)
212+	0.706	1.87
180+	1.152	3.48

Sieve Size (μm)	Firmness (kg)	Work of Shear (kg·sec)
150+	0.704	1.76
95+	0.843	2.53
95–	1.036	2.80

3.9 Sensory Evaluation

Sensory scores for ragi dosa (Table 14) were highest for the 150 μm fraction across every attribute, namely appearance (8.80), colour (8.70), taste (8.80), texture (8.90), and overall acceptability (8.90), while the coarsest (212 μm) fraction was consistently rated lowest. For vermicelli (Table 15), the 95+ μm fraction was preferred overall, scoring highest for appearance (8.90), colour (8.90), texture (8.90), and overall acceptability (8.90), although the 150 μm fraction scored marginally higher for taste (8.50 vs. 8.80 for 95+, the highest taste score recorded). As with dosa, the coarsest (212 μm) fraction was rated lowest across all sensory attributes for vermicelli. Notably, the particle size preferred by sensory panellists for dosa (150 μm) does not coincide with the fraction offering the highest fibre, protein, or ash retention (which favoured coarser flour), underscoring the trade-off between nutritional density and consumer-perceived eating quality that must be balanced when formulating a commercial product.

Table 14. Sensory Evaluation Scores for Ragi Dosa (9-Point Hedonic Scale)

Attribute	212 μm	180 μm	150 μm	95+ μm	95– μm
Appearance	7.40	7.80	8.80	8.10	8.20
Colour	7.30	7.70	8.70	8.50	8.30
Taste	7.20	7.90	8.80	8.50	8.00
Texture	7.10	7.80	8.90	8.60	8.20
Overall Acceptability	7.30	7.90	8.90	8.50	8.20

Table 15. Sensory Evaluation Scores for Ragi Vermicelli (9-Point Hedonic Scale)

Attribute	212 μm	180 μm	150 μm	95+ μm	95– μm
Appearance	7.20	7.80	8.40	8.90	8.30
Colour	7.00	7.60	8.30	8.90	8.50
Taste	7.30	7.90	8.50	8.80	8.00
Texture	7.20	8.00	8.60	8.90	8.20
Overall Acceptability	7.20	7.90	8.50	8.90	8.20

4. Conclusion

This study demonstrated that flour particle size significantly influences the nutritional, functional, rheological, textural, and sensory properties of ragi flour and its derived products. Moisture content remained essentially uniform across all fractions, but coarser fractions (212-180 μm) retained more protein, crude fibre, and ash, reflecting a greater proportion of bran and germ material. Finer fractions showed lower water activity and a lighter colour, while intermediate and coarser fractions displayed higher alkaline water absorption, alkaline water solubility, and batter viscosity.

Product quality was similarly shaped by particle size: texture profile analysis showed that the finest flour (95– μm) produced the firmest, most cohesive dosa, whereas the 180 μm fraction produced the firmest vermicelli. Sensory evaluation, however, identified the 150 μm fraction as most preferred for dosa and the 95+ μm fraction as most acceptable for vermicelli, indicating that instrumentally firmer or more nutrient-dense fractions do not always align with the fractions consumers prefer. Taken together, these findings suggest that intermediate particle size fractions offer the best overall balance between nutritional quality, processing characteristics, texture, and consumer acceptability, and that careful selection of flour granulation, tailored to the specific product, is an effective strategy for optimizing the quality of value-added ragi-based foods.

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