Functional Properties of Millet Flours and Their Applications in Product Innovation

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ABSTRACT

Millets are nutrient-dense, climate-resilient grains with the potential to address micronutrient deficiencies and lifestyle-related disorders while supporting sustainable food systems. Among them, ragi (Eleusine coracana), foxtail millet (Setaria italica), and pearl millet (Pennisetum glaucum) are notable for their high calcium, dietary fiber, iron, and polyphenol content, which contribute to improved digestive health and metabolic balance. Beyond their nutritional advantages, millets exhibit diverse functional properties including water and oil absorption, viscosity, foaming capacity and bulk density. This study examined the functional characteristics, including viscosity, bulk density, water absorption capacity (WAC), and oil absorption capacity (OAC), of selected millet flours (ragi, foxtail, and pearl millet). Millets showed favourable functional profiles: ragi showed the highest water absorption (227%) and foaming capacity (12.5%), ideal for moist and aerated foods; foxtail millet exhibited the greatest bulk density (0.90g/mL), suited for extruded snacks. These findings confirmed the versatility of millets as functional ingredients in a variety of innovative food products.

Keywords: Millets, Functional properties, ragi, foxtail millet, pearl millet

INTRODUCTION

Millets, often referred to as "nutri-cereals," are among the oldest cultivated grains and play a crucial role in ensuring food and nutritional security across many regions of the world (Obilana & Manyasa, 2002; Rao & Basavaraj, 2015). These small-seeded cereals, including ragi (Eleusine coracana), foxtail millet (Setaria italica), and pearl millet (Pennisetum glaucum), are known for their resilience to harsh climatic conditions and ability to thrive in low-input farming systems (Saleh et al.,2013). Compared to major cereals such as rice and wheat, their cultivation requires less water and fertilizer, making them a sustainable choice in the context of climate change and global food challenges (Chandra, Chandra, & Sharma, 2015). Nutritionally, millets are superior to several staple cereals. They are rich in complex carbohydrates, dietary fiber, essential amino acids, vitamins, and minerals such as calcium and iron (Singh et al., 2012; Annapurna & Andallu, 2022; Annapurna et al., 2024). Research studies indicate that the nutritive value of millets can be enhanced by processing methods like germination and fermentation (Tripathi et al., 2021; Annapurna et al., 2024). Their low glycemic index and high antioxidant content make them particularly effective in managing lifestyle-related disorders, including diabetes, cardiovascular diseases, and obesity (Saleh et al., 2013). Due to these health-promoting properties, millets are increasingly recognized as functional foods with significant potential to address malnutrition and chronic diseases (Chandra et al., 2015).

Beyond their nutritive profile, millets exhibit diverse functional properties that strongly influence their application in food systems. Parameters such as water absorption capacity (WAC), oil absorption capacity (OAC), foaming capacity, bulk density, and viscosity play a decisive role in determining product formulation, texture, stability, and consumer acceptability (Sosulski et al., 1976; Narayana & Narasinga Rao, 1982). For example, higher water absorption supports bakery and porridge preparations, oil absorption enhances flavor retention and mouthfeel, and foaming ability is critical for aerated foods. Bulk density directly affects packaging efficiency and processing, while viscosity determines suitability for products like porridges, soups, and weaning foods (Adebowale, Sanni, & Oladapo, 2005). These functional attributes not only define the role of millets in traditional diets but also expand their potential in modern product development. With increasing consumer demand for nutritious, plant-based, and sustainable food options, understanding these properties is essential for designing innovative millet-based formulations that meet contemporary dietary needs.

Therefore, the present study was undertaken to evaluate the functional characteristics of ragi, foxtail millet, and pearl millet flours, focusing on WAC, OAC, foaming capacity, bulk density, and viscosity. The findings are expected to provide valuable insights into their suitability for food formulation and to highlight their potential as versatile ingredients in functional and value-added product development.

MATERIALS AND METHODS

Procurement of samples:

Ragi flour (Eleusine coracana), foxtail millet flour (Setaria italica), and pearl millet flour (Pennisetum glaucum) were procured from a local store in Vijayawada, Andhra Pradesh, India. The samples were purchased in sealed packs to ensure quality and stored in airtight containers under ambient conditions until analysis. All experiments were conducted on flour samples without further milling or sieving.

Analysis of Functional Properties:

Bulk Density (BD):

Bulk density was determined using the graduated cylinder method, where a known mass of millet flour was filled into a graduated cylinder and the volume it occupied was recorded (Sosulski et al., 1976).

$$\text{Bulk Density (g/mL)} = \frac{\text{Mass of Sample (g)}}{\text{Volume occupied (mL)}}$$

Water Absorption Capacity (WAC):

WAC is measured by mixing a known weight of sample with water, allowing hydration, and quantifying the water retained after removing unabsorbed water (FSSAI Manual of Methods of Analysis of Foods, 2012).

$$\text{WAC (\%)} = \frac{\text{Weight of water absorbed (g)}}{\text{Weight of sample (g)}} \times 100$$

Oil Absorption Capacity (OAC):

OAC is determined by mixing a known weight of sample with oil, allowing absorption, and measuring the amount of oil retained after removing excess (Narayana & Narasinga Rao, 1982).

$$\text{OAC (\%)} = \frac{\text{Weight of oil absorbed (g)}}{\text{Weight of sample (g)}} \times 100$$

Foaming Capacity (FC):

FC is determined by whipping a sample suspension, measuring the initial and final volumes, and expressing the increase as a percentage (Sosulski et al., 1976).

$$\text{FC (\%)} = \frac{\text{Volume after whipping - Initial volume}}{\text{Initial volume}} \times 100$$

Viscosity:

Viscosity was determined using an Ostwald viscometer by recording the flow time of the flour suspension. Higher viscosity indicates thicker consistency, while lower viscosity suggests a more free-flowing suspension (Adebowale, Sanni, & Oladapo, 2005).

Viscosity □ Flow time (sec)

Statistical Analysis:

All experiments were carried out in triplicate, and the results are expressed as mean ± standard deviation (SD).

RESULTS AND DISCUSSION

The functional properties of ragi, foxtail millet, and pearl millet flours are summarized in Table 1. Mean values were calculated from triplicate determinations, and variability was expressed as standard deviation (SD).

Bulk Density(BD): Bulk density is defined as the mass of a flour sample per unit volume. Among the three flours, Foxtail millet recorded the highest bulk density (0.90 ± 0.02 g/mL), indicating tightly packed particles suitable for compact products like granola clusters and pasta. Ragi showed a moderate bulk density (0.80 ± 0.01 g/mL), reflecting balanced packing, useful for ready-to-cook porridges and instant mixes (Adebowale et al., 2005; Singh et al., 2012). In contrast, Pearl millet had the lowest bulk density (0.75 ± 0.01 g/mL), showing lighter packing, which is advantageous for light-textured powders and instant blends.

Water Absorption Capacity (WAC): Water Absorption Capacity is the ability of a cereal or flour to absorb and retain water, primarily due to hydrophilic components such as proteins, starches, and fibers that bind water through hydrogen bonding. This property affects dough formation, texture, and processing behaviour of food products. Ragi flour showed the highest WAC (227.0 ± 0.03%), demonstrating excellent hydration capacity, making it suitable for moisture-rich foods like kheer mixes and smoothies (Singh & Sehgal, 2008; Adebowale et al., 2005). Pearl millet displayed moderate WAC (130.2 ± 0.02%), offering balanced hydration for instant meal cups and soup mixes. On the other hand, Foxtail millet exhibited the lowest WAC (97.8 ± 0.05%), indicating poor water retention, which favours dry snack formulations and crispy items.

Oil Absorption Capacity (OAC): Oil Absorption Capacity refers to the ability of a cereal or flour to absorb and retain oil. It is mainly influenced by the presence of hydrophobic proteins and surface characteristics that allow binding of lipids. OAC plays a crucial role in enhancing flavour retention, improving mouthfeel, and extending the shelf life of food products. Ragi showed the highest OAC (131.0 ± 0.06%), supporting aerated dessert blends and fried snacks (Adebowale et at., 2005; Singh et al., 2012) with better flavor retention. Foxtail millet recorded moderate OAC (69.9 ± 0.02%), which suits low-fat snack innovations. Pearl millet had the lowest OAC (48.45 ± 0.07%), indicating minimal oil retention, suitable for healthier low-fat blends and RTC formulations

Foaming Capacity (FC): Foaming Capacity refers to the ability of proteins in a cereal or flour to form a stable foam by trapping air at the air-water interface during whipping or agitation. It depends on the solubility and flexibility of proteins, which allow them to rapidly unfold and stabilize air bubbles. Ragi exhibited the highest foaming capacity (12.5 ± 0.4%), making it useful for whipped desserts and bakery products needing a light texture. Pearl millet showed moderate FC (6.2 ± 0.3%), which is suitable for mildly aerated foods such as traditional batters. Foxtail millet had the lowest FC (2.4 ± 0.2%), indicating weak aeration ability, favouring dense-textured products like crackers and extruded snacks (Singh et al., 2012).

Viscosity: Viscosity measures the resistance of a flour suspension to flow and reflects its ability to form thick pastes or gels (Sosulski et al., 1976). It is influenced by starch composition, granule swelling, and soluble components such as proteins and fibers (Narayana & Narasinga Rao, 1982). When comparing viscosity, Ragi displayed the highest value (39 ± 0.5 sec), indicating strong thickening ability for soups, baby foods, and creamy beverages (Adebowale et at., 2005; Singh et al., 2012). Pearl millet showed intermediate viscosity (24 ± 0.7 sec), providing balanced flow for multipurpose instant meals. Foxtail millet recorded the lowest viscosity (22 ± 0.8 sec), resulting in thinner slurries suitable for instant drinks and weaning foods.

Table 1. *Functional properties of millet flours (mean ± SD)*

Functional Property	Ragi Millet Flour	Foxtail Millet Flour	Pearl Millet Flour
Bulk Density (g/mL)	0.80 ± 0.01	0.90 ± 0.02	0.75 ± 0.01
WAC (%)	227.0 ± 0.03	97.8 ± 0.05	130.2 ± 0.02
OAC (%)	131.0 ± 0.06	69.9 ± 0.02	48.45 ± 0.07
FC (%)	12.5 ± 0.4	2.4 ± 0.2	6.2 ± 0.3
Viscosity (sec)	39 ± 0.5	22 ± 0.8	24 ± 0.7

Values are expressed as mean ± standard deviation

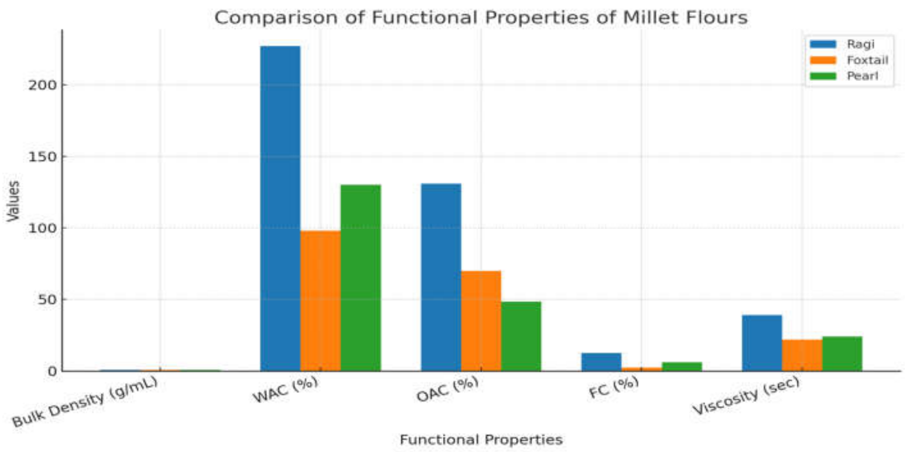

Figure 1:Graphical representation of functional properties of selected millet flours

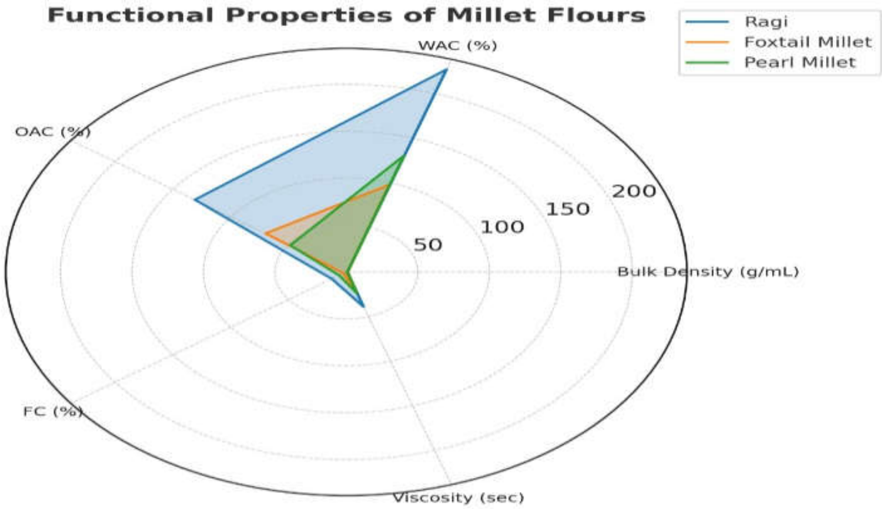

Figure 2:Radar plot representation of functional properties of selected millet flours

CONCLUSION

The present study demonstrated that ragi, foxtail millet, and pearl millet exhibit distinct functional properties that make them suitable for diverse food applications. Ragi showed superior water and oil absorption, foaming capacity, and viscosity, making it ideal for moist, aerated, and thick-consistency products. Foxtail millet, with the highest bulk density, is advantageous for compact, packaging-efficient, and extruded food formulations, while pearl millet's balanced properties support versatile applications in both traditional and modern foods. These findings highlight the potential of millets as functional ingredients for health-focused and innovative product development in the food industry.

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