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EFFECT OF PROCESSING ON NUTRIENT AND NON-NUTRIENT COMPOSITION AND FUNCTIONAL PROPERTIES OF FOXTAIL MILLET (*SETARIA ITALICA* L.) VARIETY OF ASSAM, INDIA

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ABSTRACT

The study examined the effects of different processing techniques - parboiling, roasting, soaking and steaming - on nutrient and non-nutrient composition and functional properties of foxtail millet (*Setaria italica* L.). Foxtail millet variety AAU-GSG-Cawn-1 was collected from AAU-Zonal Research Station, Gossaigaon, Assam, India. Grains were subjected to different processing treatments, dried, dehulled and ground into flour. Significant variations in nutrient and non-nutrient composition were found upon processing ($p < 0.05$). Starch, amylose, and crude protein content ranged from 61.63%-64.46%, 17.56%-20.68%, and 10.86%-12.72%, respectively. In starch digestibility, RDS, SDS, and RS fractions of processed foxtail millet starch varied from 33.92-46.63%, 31.97-37.49%, and 20.03-27.33%, respectively. Total phenolic content ranged from 120.58-161.08 mg GAE/100 g, total flavonoid content from 416.34-573.18 mg QE/100 g, tannin from 74.79-88.37 mg TAE/100 g, oxalate from 7.61-12.21 mg/100 g, and phytate from 300.45-471.25 mg/100 g. Foxtail millet flour showed distinctive functional properties upon processing. Bulk density ranged from 0.74-0.82 g/cm³, swelling capacity ranged from 11.50-15.25 ml. Water absorption capacity and oil absorption capacity varied from 125.82-149.00% and 91.83-116.07%, respectively. Emulsion activity and emulsion stability were measured at 40.07-42.14% and 38.33-39.67%, respectively. Foam capacity and foam stability were within the ranges of 1.15-3.90% and 0.39-1.18%, respectively. Least gelation concentration was recorded at 10-12%, and the gelatinization temperature ranged from 68.43-73.47 °C. The study concluded that the processing of *Setaria italica* L. significantly influenced its biochemical composition and functional properties.

***Keywords*:** Foxtail millet, processing, nutrient composition, non-nutrient composition, functional properties

Introduction

Foxtail millet (*Setaria italica* L.) is among the earliest cultivated millet crops. It originated in the Yellow River Basin region of China (Li and Wu, 1996) and is also known as Italian or German millet. It is the sixth highest-yielding grain worldwide in terms of production and stands as the second-highest millet produced globally. Foxtail millet is a leafy-stem annual grass and an important staple food, widely cultivated in semi-arid regions of Asia, Eurasia, and Africa. It is referred to as *Konidhan* in Assamese and is grown and consumed in various areas of Assam, especially in lower Assam and neighbouring northeastern states (Khatoniar and Das, 2020). Due to its unique nutritional profile, agronomic traits, resilience to climate change and economic benefits, foxtail millet is gaining attention from around the world. This whole-grain cereal is devoid of gluten and contains bioactive compounds that offer numerous health benefits and medical uses, including anti-carcinogenic, anti-oxidative, anti-inflammatory, and hypocholesterolemic

properties. It has a moderate glycemic index and slow starch digestibility, for which foxtail millet acts as a functional diet for individuals dealing with diabetes (Malavika *et al.*, 2020). Phytochemicals present in foxtail millet have supplemental therapeutic benefits for conditions such as heart disease, obesity and cancer. However, absence of gluten results in the poor processing characteristics of foxtail millet and restricts the development of its products. Food processing improves the nutritional value of food and functionality. Foxtail millet is processed before consumption to improve its sensory qualities, digestibility, and nutrient bioavailability and to reduce antinutritional factors (Nazni and Devi, 2016). The nutritional and non-nutritional composition of foxtail millet fluctuates throughout processing, and different processing techniques may have differing impacts on it. Despite being widely used, not much research has been done on the influence of common processing technologies on nutrient, non-nutrient, and functional properties of this minor millet. Research on the impact of processing on these factors is essential for future investigations. Therefore, an attempt was made to study the effects of some common processing techniques-parboiling, roasting, soaking and steaming-on the nutrient and non-nutrient composition, including its impact on the functional properties of foxtail millet variety cultivated in Assam, India.

Materials and Methods

Site of experiment

The experiments were carried out in Food Processing and Experimental Laboratory of the Department of Horticulture and Post-harvest Engineering Technology Laboratory of the Department of Agricultural Engineering, Assam Agricultural University, Jorhat, Assam, India.

Processing of foxtail millet

The foxtail millet variety 'AAU-GSG-Cawn-1', notified by the Central Variety Release Committee, was collected from AAU-Zonal Research Station, Gossaigaon, Assam, India. The grains were washed with distilled water to remove surface adhering and dirt. Excess water was drained, and grains were dried in a dehydrator (EcoTech Stainless Steel Tray Dehydrator) at 50 °C. After that, a batch of foxtail millet grains was kept untreated, while other batches of foxtail millet grains were subjected to the following processing treatments:

1. **Parboiling:** Parboiling method described by Bora *et al.* (2019) was followed. Foxtail millet grains (250 g) were soaked in water (1:3 w/v) for 12 h at room temperature. Soaked grains were put into boiling water (100 °C) and boiled for 5 min, followed by draining excess water and drying grains until moisture content of 12 % was obtained.
2. **Roasting:** Foxtail millet grains (100 g) were roasted in a pan at 120 °C for 5 min (Navyashree *et al.*, 2022). After roasting, grains were stored at room temperature (26 ± 2 °C) in a cool, dry place.
3. **Soaking:** Soaking was done as described by Sharma and Sharma (2022). Foxtail millet grains (250 g) were soaked in deionized water for 12 h at 25 ± 2°C, with a grain-to-water ratio of 1:15 (w/v). Excess water was drained. Grains were dried in dried at 50 °C until moisture content of 12% was achieved.
4. **Steaming:** Steaming process described by Azad *et al.* (2019) was followed. Foxtail millet grains (250 g) were soaked (grains: water = 1:5 w/v) for 12 h at room temperature, then steamed in an automatic steamer (USHA Steamer Automatic Rice Cooker) for 10 min at 110°C, followed by drying at 50°C.

Raw and processed grains of foxtail millet were dehulled using the Mini Rice Mill (Nabhitha Engineering Pvt. Ltd., Hyderabad), followed by grinding into flour using a hammer mill (ALFA Instruments Lab Hammer Mill). Flour samples were passed through a sieve (250 µm) to obtain uniform, fine flour. The samples were packed in airtight containers and stored at 4°C for further analysis.

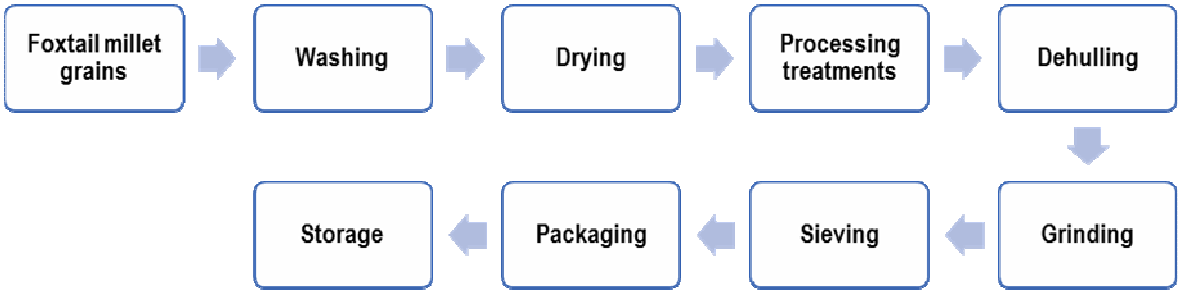
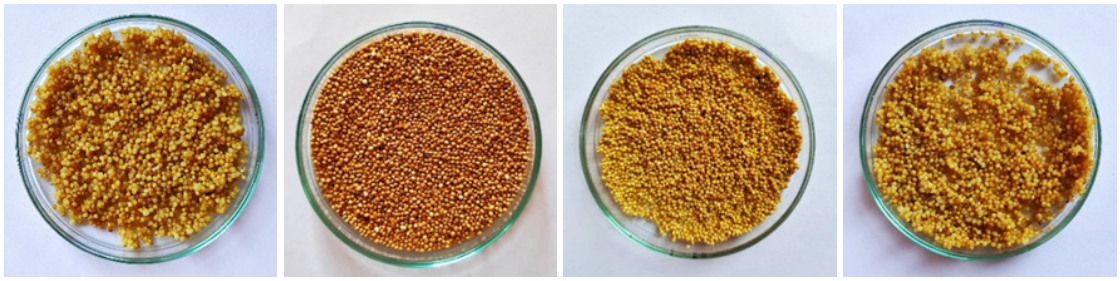


Fig. 1: Preparation of foxtail millet samples

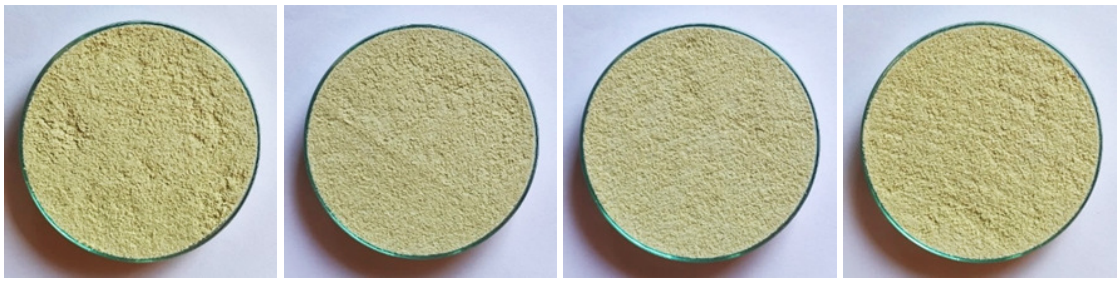
Raw grains Raw flour

Fig. 2 : Unprocessed foxtail millet grains and flour



Parboiling Roasting Soaking Steaming

Fig. 3: Processed foxtail millet grains



Parboiling Roasting Soaking Steaming

Fig. 4: Processed foxtail millet flour samples

Determination of nutrient composition

Starch content was estimated using the anthrone method described by Hedge and Hofreiter (1962). Amylose content was estimated by following the iodine colorimetric method of McCready *et al.* (1950). Crude protein of the sample was determined using the micro-kjeldahl method (AOAC, 1970).

Determination of *in vitro* starch digestibility

Starch from the raw and treated foxtail millet samples was extracted by following the alkali extraction method of Reddy and Bhotmange (2013). *In vitro* starch digestibility of starch samples was performed using the method given by Ren *et al.* (2015).

Determination of non-nutrient composition

Total phenolic content (TPC) was determined by using Folin-Ciocâlteu reagent (Bray and Thorpe, 1954). Total flavonoid contents (TFC) were determined by aluminium chloride colorimetric method as described by Chang *et al.* (2002). Total tannin content was determined by Folin-Denis method (Price and Butler, 1977). Oxalate content was determined using volumetric analysis method as outlined by Andrade *et al.* (2015). The method described by Wheeler and Ferrel (1971) was used to determine phytate content.

Determination of functional properties

Bulk density, swelling capacity, emulsion activity, emulsion stability, foaming capacity, foaming stability and gelatinization temperature were determined by following the methods outlined by Chandra *et al.* (2015). Water absorption capacity and oil absorption capacity were determined by using the method described in Al-Mhyawi and Nasser (2023). Least

gelation concentration was determined using the method described by Kakar *et al.* (2022).

Statistical Analysis

The data were subjected to analysis of variance (ANOVA). Duncan's multiple range test (DMRT) was used to determine significant differences among the treatment means at 5% probability level. All the estimates were performed in triplicate.

Results and Discussion

Nutrient composition

The nutrient composition of foxtail millet as affected by different processing methods is presented in Table 1. Starch, a polymer of α-glucose subunits, is the primary storage polysaccharide in plants. Heat-processing techniques significantly reduced the starch content of foxtail millet variety AAU-GSG-Cawn-1 compared to raw samples, while soaking had a negligible impact. Raw samples had the highest starch content of 64.46 ± 0.24%, while roasted samples had the least (61.63 ± 0.01%). The reduction may result from the modification of starch structure at high temperatures during processing, which affected the starch composition in foxtail millet. Yang *et al.* (2022) highlighted the susceptibility of starch to denaturation under high moisture and temperature conditions. The results were consistent with Nazni and Devi (2016) in roasted and hydrothermally-treated foxtail millet and Shobana and Malleshi (2007) in steamed finger millet.

Amylose is a long linear chain of 200 to 1000 D-glucose units joined by α (1-4) glycosidic linkages in starch. Amylose content was found lowest at 17.56 ± 0.01% in soaked samples, which was found *at par* with raw samples (17.68 ± 0.13%). This might result from the leaching of soluble components, including amylose, in soaking medium (Gowda *et al*., 2024). Amylose content increased with processing, with the highest value found in parboiled samples (20.68 ± 0.23%). This apparent rise in amylose concentrations might be due to the formation of amylose-amylopectin complexes during heat processing (Miraji *et al*., 2021). Also, the thermal disintegration of amylopectin might have contributed to the apparent increase in amylose content. Similar findings were reported by Dharmaraj and Malleshi (2011) in steamed finger millet, and Nazni and Devi (2016) in hydrothermally treated foxtail and barnyard millet.

Table 1: Nutrient composition of raw and processed foxtail millet

Treatments	Starch (%)	Amylose (%)	Crude protein (%)	*In vitro* Starch Digestibility		
				RDS (%)	SDS (%)	RS (%)
Raw	64.46 ± 0.24^{a}	17.68 ± 0.13^{d}	12.72 ± 0.21^{a}	46.63 ± 0.47^{a}	32.13 ± 0.38^{c}	21.22 ± 0.32^{d}
Parboiled	62.35 ± 0.17^{c}	20.68 ± 0.23^{a}	10.97 ± 0.06^{c}	33.92 ± 0.21^{b}	37.49 ± 0.31^{a}	27.33 ± 0.32^{a}
Roasted	61.63 ± 0.01^{d}	19.95 ± 0.19^{b}	10.86 ± 0.10^{c}	35.92 ± 0.63^{b}	34.81 ± 0.16^{b}	24.62 ± 0.50^{c}
Soaked	64.38 ± 0.15^{a}	17.56 ± 0.01^{d}	11.38 ± 0.10^{b}	46.03 ± 0.32^{a}	31.97 ± 0.88^{c}	20.03 ± 0.29^{d}
Steamed	63.62 ± 0.05^{b}	18.66 ± 0.18^{c}	10.92 ± 0.06^{c}	34.72 ± 1.03^{b}	37.02 ± 1.10^{a}	25.90 ± 0.48^{b}

Values are mean of three replications. Values in a row followed by different superscripts indicate significant difference ($p < 0.05$)

Proteins are essential organic compounds for the development and maintenance of the human body. Crude protein content was highest in raw samples (12.72 ± 0.21%), which was reduced during processing treatments to 11.38 ± 0.1% (soaking), 10.97 ± 0.06% (parboiling), 10.92 ± 0.06% (steaming) and 10.86 ± 0.10% (roasting). Heat processing has been reported to cause protein denaturation at high temperatures. Moreover, the losses in protein content were likely due to reduced amino acid availability during heating while speeding up the Maillard reaction (Oboh *et al*., 2010). Similar reductions have also been reported in roasted maize (Oboh *et al*., 2010), roasted foxtail millet (Sudha *et al*., 2021) and hydrothermally treated foxtail millet (Kaur *et al*., 2023). Losses of protein content were observed in soaked millet samples, likely due to leaching out of proteins in water, which were similar to the findings of Pawar and Machewad (2006) in foxtail millet.

In vitro starch digestibility

In vitro starch digestibility is an enzymatic analysis and is conducted to mimic the starch digestibility in the human digestive system for measuring starch hydrolysis rate. Starch is categorized into three main types based on its rate of glucose release and extent of digestion in the intestinal tract: rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) (Englyst *et al.*, 1992). The highest RDS content observed was 46.63 ± 0.47% in raw samples, while the lowest was recorded in parboiled samples (33.92 ± 0.21%). Soaked samples had the lowest SDS content (31.97 ± 0.88%), and parboiled samples had the highest SDS content of

37.49 ± 0.31%. Lastly, the highest RS content was found for the parboiled samples (27.33 ± 0.32%), while the lowest was recorded for the soaked samples (20.03 ± 0.29%). The results are shown in Table 1.

Heat processing significantly increased RS and SDS content, with the maximum effects shown in parboiled samples, followed by steamed samples. This might be due to the retrogradation of the gelatinised starch during the cooling phase, forming retrograded starch (RS III), which resists enzymatic digestion and slows down the starch digestibility. Similar impacts of heat treatments were reported earlier on the *in vitro* starch digestibility of rice (Cheng *et al*., 2019) and pearl millet starch (Sandhu *et al*., 2020). Enhanced RS and SDS levels are considered nutritionally advantageous, contributing to lower postprandial blood glucose levels, improved colon health, and reduced plasma cholesterol, etc.

Non-nutrient composition

Foxtail millet serves as a reservoir of phytochemicals such as tannins, phenolics, enzyme inhibitors (e.g., trypsin inhibitors, α-amylase), phytates, catechins, flavonoids, etc. Table 2 shows the effect of processing on non-nutrient composition of the foxtail millet. Significant results were observed among the processing treatments ($p < 0.05$). There was a significant decrease in TPC, TFC and tannins with different processing treatments. The highest TPC was found for raw samples (161.08 ± 0.46 mg GAE/100 g), while the lowest was found in roasted samples with a phenolic content of 120.58 ± 0.32 mg GAE/100 g. The significant reduction of phenolic compounds during heat processing might result from heat-induced degradation, resulting in a lower amount of extractable phenolics. Heat influenced the stability of phenolic compounds by disrupting esterified and glycosylated linkages (Vallepu *et al*., 2023). Similar observations were recorded in the total phenolic content of roasted pearl millet (Sade, 2009), steam-cooked foxtail millet (Vallepu *et al*., 2023), and soaked pearl millet (Sihag *et al*., 2015). Flavonoids belong to the group of polyphenolic compounds, primarily found as flavone glycosides or flavone aglycones. The highest TFC was found for raw samples (573.18 ± 0.09 mg QE/100 g), followed by soaked samples with a TFC of 505.15 mg QE/100 g, while steamed samples contained the least TFC (416.34 ± 0.07 mg QE/100 g). The breakdown of heat-sensitive molecules, hydrolysis of flavonoid glycosides to free aglycones, and deglycosylation of flavonoids could be the contributing factors to the drop in flavonoid content during heat processing (Manikpuri *et al.*, 2023). Such reductions in total flavonoid contents were also observed in roasted maize (Oboh *et al.*, 2010) and pan-roasted kodo millet (Singh *et al.*, 2024). Soaking treatment also caused losses of these compounds, possibly due to leaching of these compounds in water. However, the losses of these compounds in soaking treatment were less, which might be due to its mild processing conditions compared to thermal processing. Tannins, also known as tannoids, are polyphenolic compounds that showed significant variations across the treatments, with the lowest in the parboiled samples (74.79 ± 0.28 mg TAE/100 g) and highest in raw samples (88.37 ± 0.56 mg TAE/100 g). Most of the bioactive compounds were reported to be unstable in heat and got rapidly solubilised (Nithya *et al.*, 2007). Similar findings were reported by Nazni and Devi (2016) in the reduction of tannins in foxtail millet upon boiling and roasting. The leaching of water-soluble tannins in water might have decreased the tannin concentrations in soaked samples (Bhuvaneshwari *et al.*, 2020).

Oxalates may function as a buffer system in plant tissues. Food high in oxalate binds to iron, calcium and magnesium, making these minerals inaccessible and causing deficiencies (Purohit *et al.*, 2023). It also hinders peptic digestion by building compounds with proteins and can cause kidney stones. Raw samples had the highest oxalate content of 12.21 ± 0.06 mg/100 g. The lowest oxalate content was found in steamed samples (7.61 ± 0.24 mg/100g). Soaking treatment resulted in a considerable loss of oxalates through leaching. Wet and dry heat treatments also reduced oxalate levels, possibly due to the thermolabile nature of antinutrients, as stated by Makinde and Akinoso (2014). Mitigation of the oxalates through processing was reported earlier in boiled and steamed vegetables (Chai and Liebman, 2005) and roasted finger millet (George *et al.*, 2023). Phytic acid or phytate is the primary form of phosphorus storage in seeds. Phytic acid possesses the capability to form insoluble complexes with vital metal ions and reduce the bioavailability of cations (magnesium, zinc, iron, and calcium). Processing resulted in a decrease in the phytate content. The least phytate content was found in the steamed samples (300.45 ± 0.08 mg/100 g), and the highest was found in raw samples (471.25 ± 0.64 mg/100 g). Heat processing treatments led to a significant reduction in phytate content. This reduction might be due to the degradation of inositol hexaphosphate into pentatetraphosphate at high-temperature conditions (Manikpuri *et al.*, 2023). The results were comparable to the findings of roasted foxtail millet (Khapre *et al.*, 2016); soaked and steamed pearl millet (Sihag *et al.*, 2015).

Table 2: Non-nutrient composition of raw and processed foxtail millet

Treatments	TPC (mg GAE/100 g)	TFC (mg QE/100 g)	Tannin (mg TAE/100 g)	Oxalate (mg/100 g)	Phytate (mg/100 g)
Raw	161.08 ± 0.46^{a}	573.18 ± 0.09^{a}	88.37 ± 0.56^{a}	12.21 ± 0.06^{a}	471.25 ± 0.64^{a}
Parboiled	136.58 ± 0.29^{d}	434.71 ± 0.01^{d}	74.79 ± 0.28^{e}	9.29 ± 0.12^{c}	383.27 ± 0.08^{c}
Roasted	120.58 ± 0.32^{e}	467.84 ± 0.03^{c}	79.86 ± 0.28^{c}	11.60 ± 0.14^{b}	360.43 ± 0.10^{d}
Soaked	145.83 ± 0.36^{b}	505.15 ± 0.01^{b}	83.23 ± 0.37^{b}	9.67 ± 0.09^{c}	410.35 ± 0.19^{b}
Steamed	141.27 ± 0.47^{c}	416.34 ± 0.07^{e}	78.45 ± 0.74^{d}	7.61 ± 0.24^{d}	300.45 ± 0.08^{e}

Values are mean of three replications. Values in a row followed by different superscripts indicate significant difference ($p < 0.05$)

Functional Properties

The functional properties of the processed millet samples are illustrated in Table 3. Bulk density (BD) is a crucial parameter to consider when designing storage structures and is determined by the degree of compactness in the packaging. Effect of processing on bulk density of the millet flour was found significant ($p < 0.05$). Raw and soaked millet samples showed the highest bulk density (0.82 ± 0.01 g/cm^3). The lowest values were recorded in the steamed samples (0.74 ± 0.00 g/cm^3). Heat processing significantly reduced the bulk densities of millet flour, likely due to alterations in the structure and composition of protein and starch or disruption of starch-protein and starch-starch interactions during heating (KG *et al.*, 2021). Similar findings were also reported in roasted white finger millet (Navyashree *et al.*, 2022) and hydrothermally treated foxtail millet (Kaur *et al.*, 2023). Flour with low bulk density is advantageous for the production of complementary foods, such as weaning and generic diets (Navyashree *et al.*, 2022).

Swelling capacity (SC) determines the amount that flour expands in volume in comparison to its initial volume after being soaked in water. It measures the ability of starch to absorb water and swell. The highest swelling capacity was observed in parboiled samples (15.25 ± 0.14 ml). Partial gelatinization of starch in wet heat processing might have altered its structure and made it more expandable. Chandra *et al.* (2015) also mentioned that parboiled rice flour had a higher potential to expand than raw rice flour.

Table 3: Functional properties of raw and processed foxtail millet flour

Treatments	BD (g/cm^3)	SC (ml)	WAC (%)	OAC (%)	EA (%)	ES (%)	FC (%)	FS (%)	LGC (%)	GT (°C)
Raw	0.82 ± 0.01^{a}	11.67 ± 0.17^{c}	129.48 ± 0.23^{c}	91.83 ± 0.29^{e}	42.14 ± 0.14^{a}	39.67 ± 0.33^{a}	3.90 ± 0.01^{a}	1.18 ± 0.23^{a}	10.00 ± 0.00^{a}	68.43 ± 0.15^{e}
Parboiled	0.76 ± 0.00^{bc}	15.25 ± 0.14^{a}	148.02 ± 0.49^{a}	108.23 ± 0.88^{b}	40.86 ± 0.09^{bc}	38.33 ± 0.33^{a}	2.42 ± 0.13^{b}	0.51 ± 0.13^{b}	12.00 ± 0.00^{a}	72.17 ± 0.12^{c}
Roasted	0.78 ± 0.00^{b}	12.67 ± 0.17^{b}	135.35 ± 0.35^{b}	101.35 ± 0.21^{c}	40.73 ± 0.44^{bc}	39.40 ± 0.74^{a}	1.15 ± 0.02^{c}	0.39 ± 0.01^{b}	12.00 ± 0.00^{a}	73.47 ± 0.29^{a}
Soaked	0.82 ± 0.01^{a}	11.50 ± 0.29^{c}	125.82 ± 0.44^{d}	95.74 ± 0.30^{d}	41.30 ± 0.30^{ab}	39.30 ± 0.30^{a}	3.86 ± 0.05^{a}	0.59 ± 0.18^{b}	12.00 ± 0.00^{a}	70.10 ± 0.06^{d}
Steamed	0.74 ± 0.00^{c}	15.17 ± 0.17^{a}	149.00 ± 1.00^{a}	116.07 ± 0.32^{a}	40.07 ± 0.54^{c}	38.67 ± 0.33^{a}	2.32 ± 0.05^{b}	0.76 ± 0.02^{ab}	12.00 ± 0.00^{a}	72.80 ± 0.20^{b}

Values are mean of three replications. Values in a row followed by different superscripts indicate significant difference ($p < 0.05$)

Amount of water flour can absorb to reach the desired consistency and produce a high-quality final product is known as water absorption capacity (WAC). It was found highest in the steamed samples ($149 \pm 1.00\%$), while the lowest was found in the soaked samples ($125.82 \pm 0.44\%$). Variations among the processing treatments were found significant ($p < 0.05$). Higher water absorption capacities in steamed millet samples was likely due to protein denaturation and unfolding of proteins during heat processing, exposing its hydration sites, which facilitate interactions with water molecules (Byarugaba *et al.*, 2023). Similar trends were also observed in parboiled foxtail millet (KG *et al.*, 2021) and microwave-roasted sorghum (Sharanagat *et al.*, 2019). This property is crucial in creating ready-to-eat food products (Chandra *et al.*, 2015).

Oil absorption capacity (OAC) is the ability of food to entrap oil through a sophisticated capillary system. The oil keeps the flavour in the mouth and increases the mouthfeel. The highest oil absorption capacity was observed in steamed samples ($116.07 \pm 0.32\%$), whereas the minimum was recorded in raw samples ($91.83 \pm 0.29\%$). This might be due to

alterations in starch and protein structure and composition during processing. High oil absorption capacity is important for enhancing the flavour and mouthfeel of food, particularly baked products (Munshi and Dashora, 2024).

Emulsion activity (EA) is correlated with the capacity of proteins to facilitate the production of an emulsion, while the ability of proteins to give an emulsion strength for stress resistance is reflected by emulsion stability (ES). EA was found to decrease with processing treatments. The highest emulsion activity was found in raw samples (42.14 ± 0.14%), while the lowest was shown in steamed samples (40.07 ± 0.54%). ES was highest in raw samples (39.67 ± 0.33%), however, ES of samples was found non-significant. Protein denaturation at elevated temperatures was reported to limit protein availability for emulsifying actions (Navyashree *et al.*, 2022). This modified native protein structure in heat-processed foxtail millet samples might have resulted in the formation of insoluble aggregations that intensified the loss in surface adsorption characteristics (Náthia-Neves *et al.*, 2023).

Foam capacity (FC) refers to the amount of interfacial area that protein can produce, whereas foam stability (FS) refers to the protein's ability to remain stable under gravitational and mechanical forces. Foam capacity and stability were found to decrease with processing treatments. The highest FC was found in raw samples (3.90 ± 0.01%), while the least FC was recorded in roasted samples (1.15 ± 0.02%). The highest FS was found in raw samples (1.18 ± 0.23%), while the least FS was observed in roasted samples (0.39 ± 0.01%). Several factors, such as the protein and carbohydrate content of flour, have been reported to affect these foam properties (Awuchi *et al.*, 2019). Changes in native protein during processing might have favoured protein cross-linking and strong disulfide bonds that limited the solubility and flexibility of proteins for foam formation and stabilization (Khan *et al.*, 2011). Similar results were found in flour obtained from roasted white finger millet (Navyashree *et al.*, 2022).

Least gelation concentration (LGC) is the ability of the starch to form gel when heated as a result of expansion and hydration of starch granules. LGC is influenced by relative ratios of components like proteins, lipids, and carbohydrates. Least gelation concentration ranged from 10 to 12%, however, non-significant variations were found among millet samples. Higher gelation concentration found in processed foxtail millet samples compared to the raw samples was likely due to variations in the structure and composition of starch during processing conditions. Sade (2009) reported similar results in pearl millet.

Gelatinization temperature (GT) is the temperature at which food starch molecules lose their structure and release as swollen amylose from the granules. Gelatinization temperature of the millet samples ranged from 68.43 ± 0.15 to 73.47 ± 0.29 °C, with the highest temperature found in roasted samples and lowest found in raw samples. Heat processing treatments enhanced the gelatinization temperatures, likely due to alterations in starch structure, enhancing its thermodynamic stability that resisted gelatinization. The findings were similar for roasted sorghum (Ranganathan *et al.*, 2013) and roasted highland barley (Zhao *et al.*, 2020).

Conclusion

Processing techniques significantly altered the nutritional and non-nutritional composition of foxtail millet variety AAU-GSG-Cawn-1. Soaking was found superior over the thermal treatments, with minimal loss of nutrients (starch and protein) and non-nutrients (total phenolics, total flavonoids and tannins). Parboiling emerged as an optimal technique for enhancing SDS and RS content and preserving the amylose content. Steaming was the most effective treatment for reducing antinutritional factors (oxalates and phytates). Wet heat processing significantly improved the functional parameters of foxtail millet flour - swelling capacity, water absorption capacity, oil absorption capacity, and gelatinization temperature. Processing was found to negatively influence the emulsion and foaming properties of foxtail millet flour. The findings from this study can assist both researchers and food industries in formulating value-added gluten-free foxtail millet products that have the potential to aid in the management of lifestyle-related health issues such as diabetes, heart disease, high blood pressure, cognitive impairment, cancer, and other non-communicable diseases.

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Conflict of interest

All authors have declared no conflicts of interest.

References

AOAC. (1970). *Official Methods Of Analysis*. Association of Official Agricultural Chemists, 11th ed., Washington D. C., USA.

Al-Mhyawi, E. K. and Nasser, J. M. (2023). Physical and functional properties of some millet cultivars in Iraq. *IOP Conf. Ser. Earth Environ. Sci.*, **1225**, 012036.

Andrade, S. C.; Oliveira, S. F.; Guiné, R. P. F. and Correia, P. M. R. (2015). Determination of some chemical properties of uncommon flours. *Int. J. Agric. Biol. Eng*., **9**, 295- 298.

Awuchi, C. G.; Igwe, V. S. and Echeta, C. K. (2019). The functional properties of foods and flours. *Int. J. Adv. Acad. Res.*, **5**(11), 139-160.

Azad, M. O. K., Jeong, D. I., Adnan, M., Salitxay, T., Heo, J. W., Naznin, M. T., Lim, J. D., Cho, D. H., Park, B. J. and Park, C. H. (2019). Effect of different processing methods on the accumulation of the phenolic compounds and antioxidant profile of broomcorn millet (*Panicum miliaceum* L.) flour. *Foods*, **8**, 230.

Bhuvaneshwari, G., Nirmalakumari, A. and Kalaiselvi, S. (2020). Impact of soaking, sprouting on antioxidant and anti-nutritional factors in millet grains. *J. Phytol.*, **12**, 62–66.

Bora, P., Ragaee, S. and Marcone, M. (2019). Effect of parboiling on decortication yield of millet grains and phenolic acids and *in vitro* digestibility of selected millet products. *Food Chem.*, **274**, 718–725.

Bray, H. G. and Thorpe, W. (1954). Analysis of phenolic compounds of interest in metabolism. *Methods Biochem. Anal.,* 27-52.

Byarugaba, R., Nabubuya, A., Muyonga, J. and Mwakha, A. (2023). Effects of roasting conditions on the proximate composition and functional properties of common bean (*Phaseolus vulgaris*) flours. *Tanz. J. Sci.*, **49**, 546–558.

Chai, W. and Liebman, M. (2005). Effect of different cooking methods on vegetable oxalate content. *J. Agril. Food Chem.*, **53**, 3027–3030.

Chandra, S.; Singh, S. and Kumari, D. (2015). Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuits. *J. Food Sci. Technol.*, **52**(6), 3681–3688.

Chang, C., Yang, M., Wen, H. and Chern, J. (2002). Estimation of total flavonoid content in propolis by two complementary colorimetric methods. *J. Food Drug Anal.*, **10**, 178-182.

Cheng, K. C., Chen, S. H. and Yeh, A. I. (2019). Physicochemical properties and *in vitro* digestibility of rice after parboiling with heat moisture treatment. *J. Cereal S.*, **85**, 98–104.

Dharmaraj, U. and Malleshi, N. G. (2011). Changes in carbohydrates, proteins and lipids of finger millet after hydrothermal processing. *LWT – Food Sci. Technol.*, **44**, 1636–1642.

Englyst, H. N., Kingman, S. M. and Cummings, J. H. (1992). Classification and measurement of nutritionally important starch fractions. *Eur. J. Clin. Nutr*., **46**, S33-50.

George, N., Mildred, N., Wanzala, E., Munga, J., Oduori, C., Kinyuru, J. and Hudson, N. (2023). Nutritional composition and anti-nutrient levels in raw and processed varieties of finger millet promoted for nutritional security. *Food Nutr. Sci.*, **14**, 1183–1205.

Gowda, N.A.N., Kambhampati, V., Pulivarthi, M. K., Chauhan, R., Pandiselvam, R. and Farahnaky, A. (2024). Thermal and non-thermal bioprocessing, A comprehensive review on millet starch properties and digestibility. *J. Food Meas. Charact.,* doi, 10.1007/s11694-024-02998-6.h

Hedge, J.E. and Hofreiter, B.T (1962). In, *Methods in Carbohydrate Chemistry*, 17, Whistler, R.L. and Be Miller, J.N., (Eds.), Academic Press, New York, p. 420.

Kakar, A.; Miano, T. F.; Soomro, A. H.; Yar, A.; Memon, S. A. and Khan, B. (2022). Oil and water absorption capacity of wheat, rice and gram flour powders. *Int. J. Ecosyst. Ecol. Sci.*, **12**, 585-594.

Kaur, T., Panesar, P. S. and Riar, C. S. (2023). Combined effect of hydrothermal treatments and drying temperature on the physicochemical, milling, and nutritional characteristics of foxtail millet. *J. Cereal Sci.*, **114**, 103788.

KG, A.; Rao, M. V.; CK, S.; Rawson, A. and Mohan, R. J. (2021). Effect of parboiling treatment on de-husking of foxtail millet (*Setaria italica* L.). *Int. J. Chem. Stud.*, **9**(1), 2352–2356.

Khapre, A., Shere, D. M. and Deshpande, H. W. (2016). Studies on effect of roasting on nutritional and anti-nutritional components of foxtail millet (*Setaria italica*).

Khan, S. H., Butt, M. S., Sharif, M. K., Sameen, A., Mumtaz, S. and Sultan, M. T. (2011). Functional properties of protein isolates extracted from stabilized rice bran by microwave, dry heat, and parboiling. *J. Agric. Food Chem.*, **59**, 2416–2420.

Khatoniar, S. and Das, P. (2020). Physical and functional properties of some millet varieties of Assam. *Int. J. Curr. Microbiol. Appl. Sci*., **9**(5), 1508-1515.

Li, Y. and Wu, S. (1996). Traditional maintenance and multiplication of foxtail millet (*Setaria italica* L. P. Beauv.) landraces in China. *Euphytica,* **87**, 33-38.

Makinde, F. M. and Akinoso, R. (2014). Comparison between the nutritional quality of flour obtained from raw, roasted and fermented sesame (*Sesamum Indicum* L.) seed grown in Nigeria. *Acta Sci. Pol. Technol. Aliment.*, **13**, 309–319.

Malavika, M., Shobana, S., Vijayalakshmi, P., Ganeshjeevan, R., Gayathri, R., Kavitha, V., Gayathri, N., Savitha, R., Unnikrishnan, R, Anjana, R. M., Malleshi, N. G., Krishnaswamy, K., Henry, C. J., Mohan, V. and Sudha, V. (2020). Assessment of quality of minor millets available in the south Indian market and glycaemic index of cooked unpolished little and foxtail millet. *Indian J. Med. Res*., **152**(4), 401-409.

Manikpuri, S., Kheto, A., Sehrawat, R. and Gul, K. (2023). How superheated steam treatment modifies the physicochemical, functional, nutritional, and anti-nutritional attributes, A case study on guar bean flour. *Innov. Food Sci. Emerg. Technol.*, **88**, 103422.

McCready, R. M.; Guggolz, J.; Siliviera, V. and Owens, H. S. (1950). Determination of starch and amylose in vegetables. *Anal. Chem*., **22**(9), 1156-1158.

Miraji, K. F., Linnemann, A. R., Fogliano, V., Laswai, H. S. and Capuano, E. (2021). Dry-heat processing at different conditions impact the nutritional composition and *in vitro* starch and protein digestibility of immature rice-based products. *Food Funct.*, **12**, 7527–7545.

Munshi, M. and Dashora, K. (2024). Comparative study of physico-chemical composition, functional, morphological and pasting properties of major and minor millet flours as a gluten free alternative to wheat flour. *Meas. Food*, **16**, 100202.

Náthia-Neves, G., Calix-Rivera, C. S., Villanueva, M. and Ronda, F. (2023). Microwave radiation induces modifications in the protein fractions of tef flours and modulates their derived techno-functional properties. *Int. J. Biol. Macromol.*, **253**, 126908.

Navyashree, N., Sengar, A. S., Sunil, C. K. and Venkatachalapathy, N. (2022). White finger millet (KMR-

340), A comparative study to determine the effect of processing and their characterisation. *Food Chem.*, **374**, 131665.

Nazni, P. and Devi, S. R. (2016). Effect of processing on the characteristics changes in barnyard and foxtail millet. *J. Food Process. Technol.*, **7**, 1000566.

Nithya, K. S., Ramachandramurty, B. and Krishnamoorthy, V. V. (2007). Effect of processing methods on nutritional and anti-nutritional qualities of hybrid (COHCU-8) and traditional (CO7) pearl millet varieties of India. *J. Biol. Sci*., **7**, 643-647.

Oboh, G., Ademiluyi, A. O. and Akindahunsi, A. A. (2010). The effect of roasting on the nutritional and antioxidant properties of yellow and white maize varieties. *Int. J. Food Sci. Technol.*, **45**, 1236–1242.

Pawar, V. D. and Machewad, G. M. (2006). Processing of foxtail millet for improved nutrient availability. *J. Food Process. Preserv.,* **30**, 269-279.

Price, M. L. and Butler, L. G. (1977). Rapid visual estimation and spectrophotometric determination of tannin content of sorghum grain. *J. Agric. Food Chem.*, **25**(6), 1268- 1273.

Purohit, P., Rawat, H., Verma, N., Mishra, S., Nautiyal, A., Anshul, Bhatt, S., Bisht, N., Aggarwal, K., Bora, A., Kumar, H., Rawal, P., Kumar, A., Kapoor, R., Sehrawat, J., Rather, M. A., Naik, B., Kumar, V., Rustagi, S., Preet, M. S., Jha, A. K. and Gupta, A. K. (2023). Analytical approach to assess anti-nutritional factors of grains and oilseeds, A comprehensive review. *J. Agric. Food Res.*, **14**, 100877.

Ranganathan, V., Nunjundiah, I. T. and Bhattacharya, S. (2013). Effect of roasting on rheological and functional properties of sorghum flour. *Food Sci. Technol. Int.*, **20**.

Reddy, D. K. and Bhotmange, M. G. (2013). Isolation of starch from rice (*Oryza Sativa* L.) and its morphological study using scanning electron microscopy. *Int. J. Agric. Food Sci. Technol.*, **4**, 859-866.

Ren, X., Chen, J., Molla, M. M., Wang, C., Diao, X. and Shen, Q. (2015). *In vitro* starch digestibility and *in vivo* glycemic response of foxtail millet and its products. *Food Funct.*, **7**(1), 372–379.

Sade, F. O. (2009). Proximate, antinutritional factors and functional properties of processed pearl millet (*Pennisetum glaucum*). *J. Food Technol.*, **7**(3), 92-97.

Sandhu, K. S., Siroha, A. K., Punia, S. and Nehra, M. (2020). Effect of heat moisture treatment on rheological and in vitro digestibility properties of pearl millet starches. *Carbohydr. Polym. Technol. Appl.,* 1.

Sharanagat, V. S., Suhag, R., Anand, P., Deswal, G., Kumar, R., Chaudhary, A., Singh, L., Kushwah, O. S., Mani, S., Kumar, Y. and Nema, P. K. (2019). Physico-functional, thermo-pasting and antioxidant properties of microwave roasted sorghum [*Sorghum bicolor* (L.) Moench]. *J. Cereal Sci.*, **85**, 111–119.

Sharma, R. and Sharma, S. (2022). Anti-nutrient & bioactive profile, *in vitro* nutrient digestibility, techno-functionality, molecular and structural interactions of foxtail millet (*Setaria italica* L.) as influenced by biological processing techniques. *Food Chem.*, **368**, 130815.

Shobana, S. and Malleshi, N. G. (2007). Preparation and functional properties of decorticated finger millet (*Eleusine coracana*). *J. Food Eng.*, 79, 529-538.

Sihag, M. K., Sharma, V., Goyal, A., Arora, S. and Singh, A. K. (2015). Effect of domestic processing treatments on iron, β-carotene, phytic acid and polyphenols of pearl millet. *Cogent Food Agric.*, 1109171.

Singh, D. K., Kurichh, R., Bist, Y., Kheto, A., Kumar, Y., Sharma, R., Shikha, D. and Saxena, D. C. (2024). Effect of microwave roasting on the physicochemical, functional, rheological, and antioxidant properties of kodo millet flour. *J. Food Process. Preserv.,* doi, 10.1155/ 2024/ 6861190

Sudha, K. V., Karakannavar, S. J., Yenagi, N. B. and Inamdar, B. (2021). Effect of roasting on the physicochemical and nutritional properties of foxtail millet (*Setaria italica*) and Bengal gram dhal flours. *Pharma Innov.*, **10**(5), 1543-1547.

Vallepu, S., Shaik, K. B., Shaik, N., Vadde, R., Ragimekula, N. and Patan, S. S. V. K. (2023). Influences of household processing methods on nutritional composition, anti-nutritional factors and antioxidant activities of foxtail millet. *Recent Prog. Nutr.*, **3**(4).

Wheeler, E.L. and Ferrel, R.E. (1971). A method for phytic acid determination in wheat and wheat fractions. *Cereal Chem*., **48**, 312-320.

Yang, T., Ma, S., Liu, J., Sun, B. and Wang, X. (2022). Influences of four processing methods on main nutritional components of foxtail millet, A review. *Grain Oil Sci. Technol.*, **5**(3), 156-165.

Zhao, B., Shang, J., Liu, L., Tong, L. T., Zhou, X., Wang, S., Zhang, Y., Wang, L. and Zhou, S. (2020). Effect of roasting process on enzymes inactivation and starch properties of highland barley. *Int. J. Biol. Macromol.,* **165**, 675–682.