The Pharma Innovation Journal 2023; 12(12): 3101-3109

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E):2277-7695
ISSN (P):2349-8242
NAAS Rating:5.23
TPI 2023; 12(12): 3101-3109

www.thepharmajournal.com
Received: 03-10-2023
Accepted: 06-11-2023

Variation in physico-chemical and functional properties of pre-treated finger millet grains and flours

Sreenatha A, Shalini Gaur Rudra, Amrender Kumar, Anil Dahuja and PK Sharma

Sreenatha A
Division of Food Science and Postharvest Technology, ICAR-Indian Agricultural Research Institute, New Delhi, Delhi, India

Shalini Gaur Rudra
Agricultural Knowledge Management Unit, ICAR-Indian Agricultural Research Institute, New Delhi, Delhi, India

Amrender Kumar
Division of Biochemistry, ICAR-Indian Agricultural Research Institute, New Delhi, Delhi, India

Anil Dahuja and PK Sharma
Division of Agricultural Engineering, ICAR- Indian Agricultural Research Institute, New Delhi, Delhi, India

Corresponding Author:
Sreenatha A
Division of Food Science and Postharvest Technology, ICAR-Indian Agricultural Research Institute, New Delhi, Delhi, India

Abstract
Finger millet grains are characterized by their red seed coat colouration. In view of demand for buff coloured variant, KMR-340 variety has been developed. In order to determine the physical, functional and physicochemical attributes, MR1 grains were compared with a popular variety, MR-1. Further, the effect of common pre-treatments like hydrothermal treatment, roasting, sprouting and puffing on the engineering properties (true density, bulk density, porosity, gelling concentration, pasting properties) and nutritional composition was determined. Highest true density (1417.23 kg/m^3) of grains was recorded in hydrothermally treated milky cream cultivar while popped reddish brown cultivar recorded lowest value (881.85±10.31 kg/m^3). 5.9 and 5.3 folds increased hardness was documented for reddish brown and milky creamy cultivars, respectively under hydrothermal treatment. Popped reddish brown cultivar recorded lowest tap density and highest oil absorption capacity. Highest least gelation concentration (10%) was observed for roasted flours from both the cultivars. Significant difference in pasting properties were observed among the roasted, germinated and puffed flours over native flour. Milky cream cultivar was found to have significantly higher nutrient (protein, fiber, crude fat, calcium and iron content). The germination treatment contributed positively to enhancing nutrient status among other processing methods.

Keywords: Variety, seed coat, pasting, nutrition, roasting, sprouting

Introduction
Finger millet (*Eleusine coracana*) is a nutri-cereal food of Africa and India which belongs to the family 'Poaceae' native of Ethiopia, cultivated in various regions of India and African countries as climate resilient staple crop (Hassan *et al.*, 2021) [12]. It is a gluten free small seeded nutri-cereal composed of wealthy dietary fibre, small and large scale supplements. It is non-acid forming, alkaline and having low glycemic index (Saini *et al.*, 2021) [33]. The finger millet grains are neglected and underutilized even though having nutraceutical advantages like gluten free grain with low glycemic index, (Amadou *et al.*, 2013) [1]. The grains contain a high amount of calcium which is an essential macro-nutrient necessary for growing children, pregnant women and the elderly.

The demand for finger millet in recent years is increased due to its health benefits. Pharmaceutical industries use starch extracted from finger millet in the preparation of granules for tablets and capsule (Shiihii *et al.*, 2011) [37]. Finger millet grains are found in different shapes, sizes and colours with the predominant colour being brown (Vadivoo *et al.*, 1998; Ramashia *et al.*, 2017) [41, 30]. The red colouration of finger millet seed coat has often been cited as detriment for inclusion in foods as it alters the appearance and significantly darkens the colour of foods containing this millet.

The finger millet genotypes with white colour seeds have higher protein content, whereas, the brown seeded genotypes exhibit wider variation (Das *et al.*, 2017) [4]. White finger millet varieties are preferred because of their high protein, low fibre, low tannins and higher consumer acceptability. KMR-340 is hybrid millet having protein of 11.98 g per 100 g, 392 mg per 100 g of calcium and 4.72 mg per 100 g of iron. Due to its excellent nutritional qualities and better physico-chemical properties with appealing white flour colour, it could be promising for the bakery industry (Ravishankar *et al.*, 2019) [32].

Processing techniques such as soaking, cooking, roasting, germination, popping and fermentation are routinely used for cereals grains to fulfil the nutritional needs of community through enhanced nutritional bioavailability, palatability, decreased anti-nutritional factors, extend shelf life and to improve organoleptic properties of food, (Gowda *et al* 2022) [11].

Roasting is one of the most prevalent traditional processing operations that utilises dry heat treatment. which provides beneficial effect of enhanced digestibility and edibility, increased iron content and sensory characteristics, improved functional properties and decreased anti-nutritional factors in cereals and millets (Yousaf *et al.*, 2021; Navyashree *et al.*, 2022) [43, 23].

Sprouting is a traditional processing technique that enhances the functional properties of millets and sensory attributes of food prepared out of it. During germination process, starch breaks down into maltose and dextrin due to the action of amylase which improves the bioavailability, nutritive value, physico-functional properties and reduces levels of anti-nutrients of cereals and millets (Yenasew and Urga 2023) [42].

Hydrothermal processing involves steeping the millet to its equilibrium moisture content, steaming at atmospheric or elevated pressure followed by drying. It hardens the grains and improves their milling efficiency apart from enhancing carbohydrate and protein digestibility with significant change in colour and size (Dharmaraj and Malleshi 2011; Dharmaraj *et al* 2015) [5, 8].

Popping is one of the traditional domestic methods of preparing starchy foods. It is high temperature short time (HTST) treatment that can be accomplished by imposing dry heat using a heating medium such as hot air, salt, oil or microwave radiation that produces a porous value-added health product of pleasant odour with an alluring texture. Popped millet and its flour is a ready-to-eat (RTE) product with improved nutritional value (Mishra *et al.*, 2014) [19].

The knowledge of the physical properties of grains is crucial in the design of harvesting, grading, cleaning, processing, grain handling equipment, grain storage structures and transport machinery (Singh *et al.*, 2017) [39]. The functional property of food is defined as the physical, chemical and/or organoleptic properties of food. It will be useful in new product development (Faleye *et al.*, 2013) [10]. These parameters address issues encountered during product development, especially in the bakery industry. Hence, it is critical to analyze the effect of various pre-treatments on differently coloured finger millet on its physical, functional and rheological properties. Although several publications have reported the assessment of functional properties of seeds and flours, comparative evaluation of functional properties of pre-treated finger millet is lacking. A current review of the literature shows that physical properties of finger millet grains have been conducted (Sangamithra *et al.*, 2016; Powar *et al.*, 2018; Pawar *et al.*, 2020) [34, 28, 26] when compared to processed finger millet (Mirza *et al.*, 2015; Navyashree *et al.*, 2022) [18, 23]. However, data on the physical and functional properties of differently processed finger millet grains and flours is still insufficient. This comparative study could help the food industry in predicting the behavior of differently coloured finger millet flour during various stages of processing. Hence, the current research was conducted to present essential characteristic findings for native, hydrothermally treated, roasted, germinated and puffed finger millet flours of milky cream and reddish brown colour cultivars. The objective of this study was to investigate the effect of various processing treatments on the physico-chemical properties and the functional properties of flours.

2. Materials and methods

2.1. Raw materials and preparation of samples: Bulk samples of finger millet cultivars KMR-340 (milky cream) and MR-1 (reddish brown) were provided by the Scheme Head, Small Millets, Zonal Agricultural Research Station, Mandya, University of Agricultural Sciences, Bengaluru (Karnataka, India). Thoroughly cleaned grains were used for the preparation of samples.

The germination of finger millet (Gf) was done by soaking grains for 24 h in distilled water, followed by germination inside the incubator the for 48 h at 30ºC. Germinated grains were further dried at 40ºC for 12 h in a hot air oven (Najdi Hejazi and Orsat, 2017) [21]. Hydrothermal (Hf) treatments were applied as per the method of Dharmaraj and Malleshi (2011)[5] briefly, the 2 kg grains of both the cultivars were steeped in excess water at 30±2ºC. The surface moisture of steeped grains was wiped by spreading grains on blotting paper. The grains were spread about 2 cm bed thicknesses in steel trays of dimension 45×40×0.5 cm (w×l×h). Trays were covered by aluminium foil to prevent the grains from wetting by the condensed steam. Grains were steamed in a horizontal autoclave (M/s. Tradevel Scientific Industries, New Delhi, India) at atmospheric pressure. The steamed grain was dried to moisture content around 12% (w.b) in a mechanical drier maintained at 40±5˚C.

Roasting (Rf) was accomplished using a twin screw extruder (BTPL make, Kolkata, India) at 120ºC temperature for 120 second duration (Tiwari *et al.*, 2014) [40]. Popping of finger millet (Pf) was done according to the procedure given by Malleshi and Desikachar (1981).[17] The grains were moistened to 19% moisture by sprinkling calculated amount of distilled water and grains were piled to equilibrate for 4 hours. Puffing was carried in sand heated to 270°C.

Preparation of finger millet flour

The grains given various processing treatments were milled into flour using a lab hammer mill, sieved through 100 µm sieve (BSS #150) packed in polythene bag for further analysis. The flours were stored at room temperature and analysed within 7 days.

Proximate composition

The pre-treated finger millet millets flours were analysed for their proximate composition, namely moisture, ash, fat, protein and crude fibre using method numbers 931.04, 923.03, 945.38, 2001.11 and 985.29, respectively (AOAC, 2019)[2]. Protein content was obtained by multiplying 6.25 with the nitrogen content. Total carbohydrates content was determined by the difference method.

Physical characterisation of raw and pre-treated finger millet grains

Physical properties of pre-treated grain such as 1000 grain weight, hardness, bulk density, true density and porosity (Ramashia *et al.*, 2017) [30].

Functional properties of raw and pre-treated millet flour

The functional properties like tap density, water and oil absorption capacity, dispersibility, swelling power and least gelation concentration of the raw and pre-treated millet flours were analysed using standard procedures (Dharmaraj *et. al.*, 2012) [6] in triplicates.

Statistical analysis

The final data was compiled and analyzed using SPSS 26.

The results were represented as descriptive statistics such as mean, standard deviation. Analysis of variance (ANOVA) with post-hoc test by Tukey's b method was used to test the differences among means for various parameters of different processed millet flours. The data reported in the tables are an average of triplicate.

Results and Discussion

Proximate composition of pre-treated finger millet grains

Assessing the proximate composition of flour is pivotal for understanding its nutritional significance. Moisture content governs the physical properties of grain and indicator of storage stability. Table 1 shows the results of the mean moisture content of differently processed finger millet grains. Moisture content was positively affected through G_f, whereas R_f and P_f understandably reduced the moisture content significantly in both the cultivars. The increase in moisture content of G_f may be due to the uptake of moisture during soaking to initiate metabolism reactions. While, the decrease in R_f, P_f corresponds to the water migration during roasting and puffing (Mirza *et al.*, 2015; [18] Moisture content in P_f cultivars ranged between 3.27% wb to 4.83% wb, it may be attributed to dehydration to an extremely low level of moisture content during the puffing process. The moisture present in the grain turns into steam as the vapour pressure of the grain increases and gelatinization of the starch takes place. The germination affected the crude protein content positively. The increase in protein content in Gf could be due to a reduction of starch content because of the enzymatic activity and synthesis of the amino acids after germination could also be the reason for the increment in the protein content (Yousaf *et al.*, 2021).[43] At the same time, reduction of protein content in Hf, Rf and Pf may be attributed to adverse effect of thermal energy supplied during the pre-treatment that leads to protein degradation and may be due to depletion of volatile nitrogenous compounds (Kumar *et al.*, 2019) [15] conversely crude protein content slightly increased in popped fox tile millet (Choudhury *et al.*, 2011) [3] The fibre content values of both the cultivars found to be not changed by Rf (Table 1b). However, it was higher in Gf, which could be ascribed to the synthesis of the cell wall, hemicellulose, and cellulose in more amounts during germination. The fat content was found to be reduced significantly only in Gf. (1.17±0.05 and 1.10±0.03) respectively for reddish brown and milky cream cultivars. The pre-treatment Hf, Rf and Pf did not show any changes in the values of fat content. The total carbohydrates significantly decreased in Gf and increased in Hf, Rf, and Pf (Table 1). Utilization of fat and simple sugars (generated through amylase enzyme activity) as the primary energy source during the germination process may be the cause for comparatively diminished levels of fat and carbohydrate in Gf (Najdi Hejazi and Orsat, 2017) [21]. The ash content increased significantly in Hf and Rf than Nf. The increase in ash content in Rf and Hf could be due to reduction of phytic acid caused by heat treatment. The increase in ash content in Rf and Hf could be due to proportional decrease in carbohydrates, fat and proteins caused by heat treatment. The findings were in line with the previous studies of Nakarani *et al.*, (2021) [22] Navyashree *et al.*, (2022) [23] Kaur *et al.* (2023) [14]. Calcium content increased significantly in Gf of both the cultivars. The pre-treatment had no effect on calcium content in Hf, Rf and Pf. The iron content diminished in Hf and increased in the order Gf > Pf. > Rf. The process of germination typically enhances the nutrient content and digestibility of foods, making it a suitable food-based strategy to optimize the extraction of iron and other minerals from grains (Platel *et al.*, 2010) [27] similar results were recorded in millets by Nazni and Shobana (2016) [28] Chauhan (2018) [5]. An increase in the iron content of Pf and Rf might be ascribed to thermal treatment which decreases the phytic acid content (Yousaf *et al.*, 2021) [43]. The transfer of leached iron from the roasting pan into the finger millet might also account for the rise in iron content. (Obadina *et al.*, 2016) [25].

Physical characteristics of pre-treated finger millet grains

The 1000 kernel weight is a measure of seed size. Generally, potential flour extraction or yields of grains are positively related to higher seed weight values. 1000 kernel weight of the samples under study ranged from 2.32 to 2.62 g in milky cream and 3.01 to 3.56g in reddish brown cultivar (Fig. 1). The study results recorded values for milky cream cultivar contrary to what was indicated by Ramashia *et al.* (2018) [30]. This difference in 1000 seed weight may be attributed to the moisture content of the samples as reported by Powar *et al.* (2018) [28] and also due to genotypic variation.

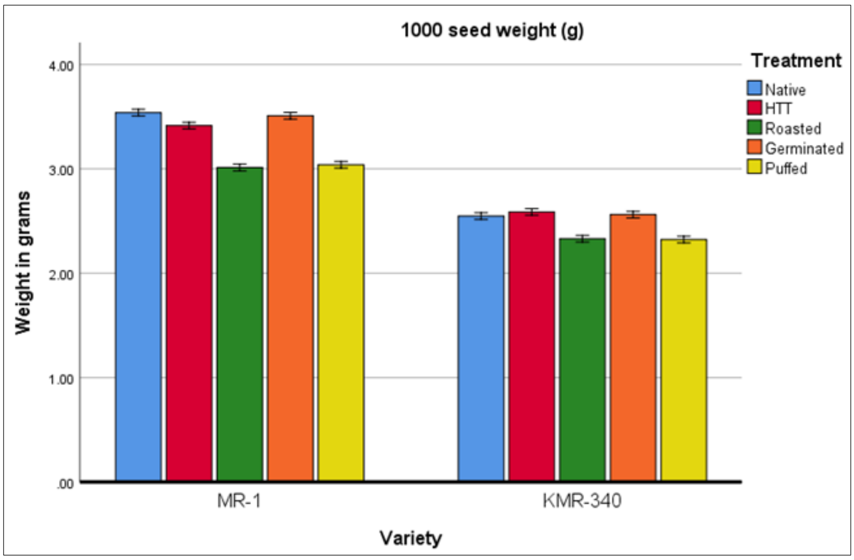

Fig 1: Effect of variety and pre-treatment on moisture content of finger millet grains.

Data presented in Table 2 shows bulk density (BD), true density (TD) and porosity of pre-treated finger millet grains. The decrease in BD of H_f may be due to lower inter-granular space because of the drying of steamed millet furrows or undulations develop on the surface of the grain. Similar results were obtained by (Dharmaraj *et al.* 2012; Rajasekar *et al.* 2018) [6, 29]. It was observed that significantly decreased BD in Gf and Pf in both the cultivars. A similar relationship was reported by Shingare and Thorat (2013) [38] 2% and 8% higher BD was observed for R_f treated reddish brown and milky creamy cultivar, respectively. The TD of H_f increased while lower TD was observed for G_f and P_f in both the cultivars. The study results recorded low for BD and TD values for milky cream cultivar compared to reddish brown cultivar which was contrary to what was indicated by Ramashia *et al.* (2017) [30].

Porosity of the both cultivars increased for all the pre-treatments. The mean porosity results varied from 33.14±0.58 to 61.64±1.05. Pf of both the cultivars exhibited higher porosity. It may be due to the irregular shape of puffed grains. Knowledge of the physical properties of grains and seeds is of preponderant in designing of handling, transportation, storing and processing equipment.

Textural attributes

Hardness and texture of millet is one of the important parameter, which plays a major role during decortication and milling (Rajasekar *et al.* 2018) [29]. Hardness of H_f increased 5.9 and 5.3 folds for reddish brown and milky creamy cultivars, respectively. Increase in hardness for H_f. is may attributed to the modified endosperm texture by removing internal voids and air gaps of the kernel by H_f (Rao and Juliano 1970) [31]. The endosperm gets filled by swollen starch granules during steaming and protein bodies disintegrate and bind to starch in the endosperm. The cell wall components get compacted and these factors case hardening of the grain. Reduced hardness by order of 7 and 3 times for P_f was recorded while not much variation was observed for the R_f and G_f (Fig 2.). Reduced hardness in Pf may be due to the changes occurred in the structural components of the finger millet due to processing conditions like the high temperature short time treatment during popping wherein the endosperm structure modified into a honey comb like structure (Dharmaraj *et al.*, 2014) [7].

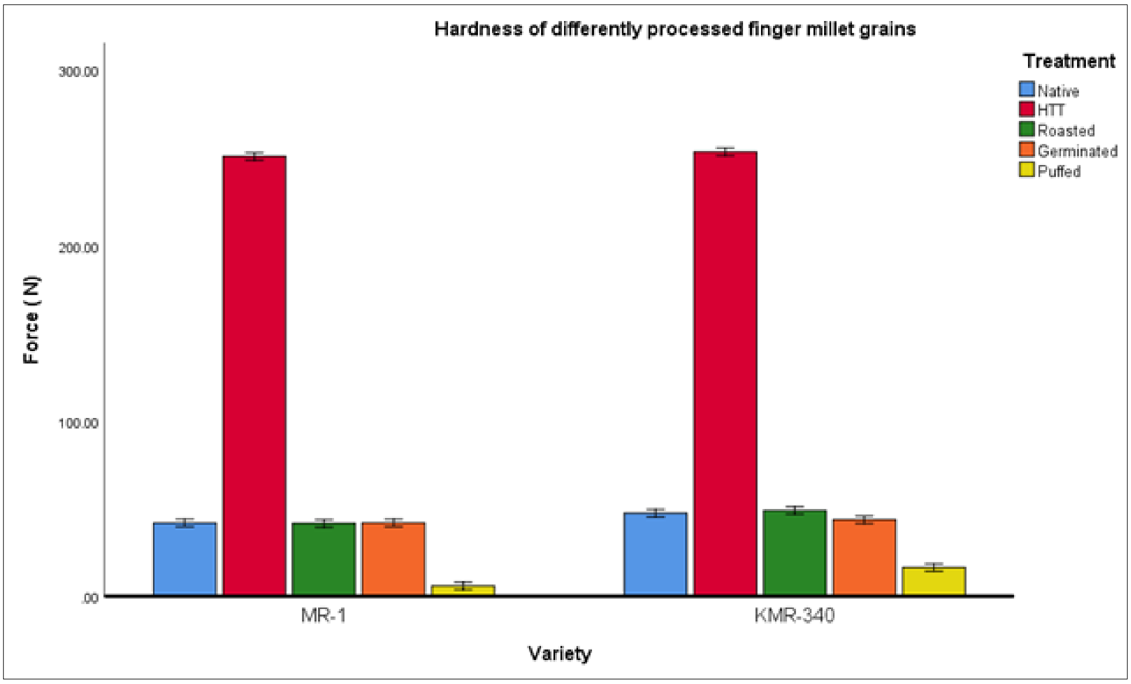

Fig 2: Hardness of processed finger millet grains

Tap density

Tap density indicates the degree of the heaviness of the flour and is influenced by the size of particles. The tap density measurements help in determination of the flow properties, designing the packaging requirements in food processing industries. Low tap density flours are preferred for the development of low cost dietary formulations. The functional properties of pre-treated finger millet flours exhibited significant variations (Table 3). The tap density of Nf 958.66±36.25 and 963.83±20.66 respectively for reddish brown and milky cream cultivars. The other processing methods were having significantly lower values of tap density. Pf was recorded with lowest tap density (570.98±4.44) among all the pre-treatments. The decrease in the tap density of R_f and P_f could be due to loss of moisture upon exposure of high temperatures. The reduction in tap density may also be due to the disintegration of the starch, starch-protein matrix. However, reduction of tap density in Gf could be attributed to breaking of complex molecules into simple due to enzymatic activity during the germination process (Sharanagat *et al.*, 2019) [36].

Water absorption capacity (WAC)

The data projected for WAC of pre-treated millet flours exhibited that the Hf, R_f and Pf flours were having increased WAC when compared with N_f. WAC of flours ranged from 2.13±0.01 to 5.46±0.13mL/g where milky cream flour had the highest value than the reddish brown cultivar. The WAC of Pf was two times higher than the N_f. The same trend was noticed in both the cultivars. The reported findings align with similar observations made by Yenasew and Urga (2023) [42] for finger millet. The increase in WAC of Hf, Pf and R_f could be due to the formation of a porous structure during dry heat an increased level of damaged starch and that adsorbs the water by capillary action. The raise in WAC may also attributed to higher amylose content (Zhiqiang *et al.*, 1999) [44]. However, the reduction of WAC in Gf may attributed to enzymatic actions which leads to cross-link formation between the degraded starch molecules in the amorphous region, could result in a reduced (Sharanagat *et al.*, 2019) [36].

Oil absorption capacity (OAC)

The OAC of Nf was 1.77±0.03 and was found to be decreased in R_f (1.72±0.09). OAC was found to be higher than Nf in other pre-treated millet flours, the maximum OAC was recorded 2.42±0.09 for Pf followed by Gf (1.98±0.08) and Hf (1.80±0.06) in reddish brown cultivar. The same trend was observed in milky cream cultivar.

The rise in OAC in Gf may be ascribed to starch hydrolysis during germination, as the hydrolyzed starch tends to absorb increased amounts of oil, or it could be due to trapping the oil between the non-polar side chains of proteins (Kumar *et al.*, 2019).[15] However, reduced the OAC in Rf attributed to the decreased non-polar amino acid content or denaturation of protein structure upon thermal treatment. WAC and OAC reveal the behaviour of flour components with water or oil that describes the flour's consistency and flavour retention ability.

Swelling power (SP)

SP reveals the capacity of starch molecules to swell after heating it in excess water. SP was lowest in Gf (4.21g/g and 4.91g/g) respectively for reddish brown and milky cream cultivars. (Table 2). Results of the present finding are in agreement with the findings of Nefale and Mashau (2018) [24] for germinated finger millet and popped foxtail millet respectively.

Dispersibility (%)

Dispersibility serves as an indicator of the capacity of flour or starch to undergo rehydration. A greater level of dispersibility corresponds to an enhanced capability of the sample to reconstitute effectively when introduced to water. Decreased dispersibility values noted in the flours suggest the possibility of the flour samples aggregating or forming clusters during the rehydration process. It reflects the interaction between the flour's composition and molecular structure (Sasaki and Matsuki 1998). [35] The dispersibility of both the cultivars was observed to be same Nf (79%). In contrast, to findings of Ramashia *et al* (2017) [30] who reported the higher dispersibility (92.03±0.38) on milky cream finger millet flour, while lower (84.73±0.64) values were obtained from brown finger millet flour. Lower values were obtained for Pf (43% and 48%) respectively for reddish brown and milky cream cultivars. No significant difference in the dispersibility of Gf, Hf and Rf. On the contrary, Yenasew and Urga (2023) [42] observed that the dispersibility of African finger millet varieties decreased as the germination period increased.

Least gelation concentration (LGC)

Gelation is an aggregation of denatured molecules. The LGC marked as + in Table 4 for pre-treated finger millet ranged between 4%-8%. N_f were having 8% LGC whereas Hf 6% and 4% LGC, Pf and Gf 8% and 6% LGC respectively for reddish brown and milky cram cultivars. R_f has shown highest LGC 10% for both the cultivars. The higher gelation concentration proved advantageous in the formulation of weaning foods, as it presented a challenge for infants to digest products that form gels at lower concentrations. Lower LGC in Hf and Pf and Gf may be attributed to denatured protein thus, caused more aggregation than in the N (Elkhalifa and Bernhardt, 2010) [9].

Pasting Properties of Finger Millet Flours

Table 5 summarises the effect of pre-treatment on pasting properties of finger millet flours. The pasting properties of finger millet flours are used to assess their appropriateness for baking applications. The peak viscosity values ranged from 305.3 to 2973 mPa.s. Peak viscosity generally relates with the quality of end-product and gives an indication of the viscous load likely to be encountered by a mixing cooker (Kaur *et al.*, 2013) [13]. Native flour had higher peak viscosity compared to other pre-treatments. Notable differences particularly in holding strength, final viscosity and setback from peak and trough were observed. Similar observation by Mudau *et al.* (2022) [20] on light and dark brown fermented finger millet. Lower final viscosity and setback from peak for KMR 30 indicates suitability for less retro gradation.

The higher peak viscosity observed in native finger millet flour was probably due to the higher content of starch (Kumar *et al.*, 2020). [16] Pasting properties of flour are influenced by its starch, protein, lipid contents and the degree of starch damage during processing of flours. Similar trend was witnessed for final viscosity values. Understandably, lower peak viscosity values were observed for the cultivars given puffing, sprouting and hydrothermal treatment (Fig.3a & 3b) indicating that they have lower thickening power. Further intermolecular bonding forces also affect swelling of starch granules and thereby the gelling characteristics of the cooked slurry. Weaker bonds in flours from puffed and hydrothermally treated grains translated to lower swelling of starches and thus lower pasting viscosities.

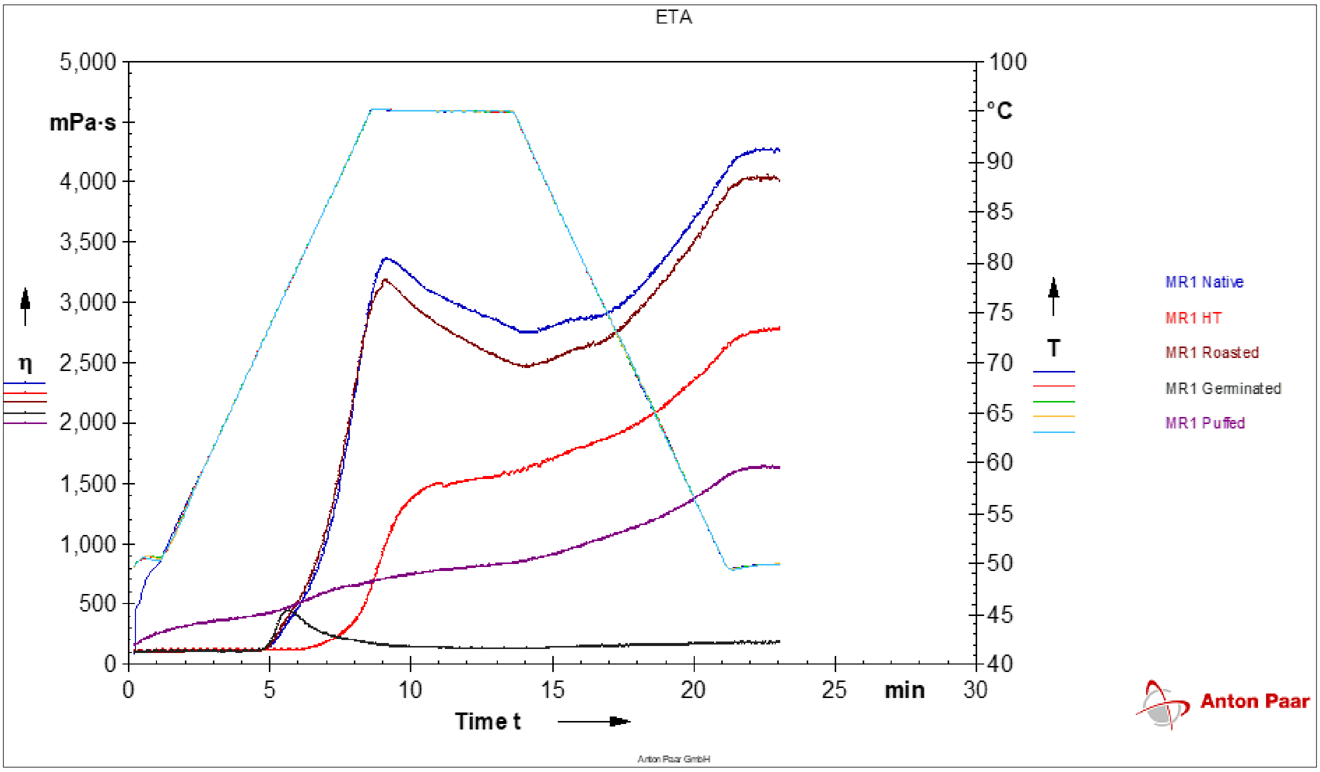

Fig 3a: RVA Patterns of reddish brown finger millet flour

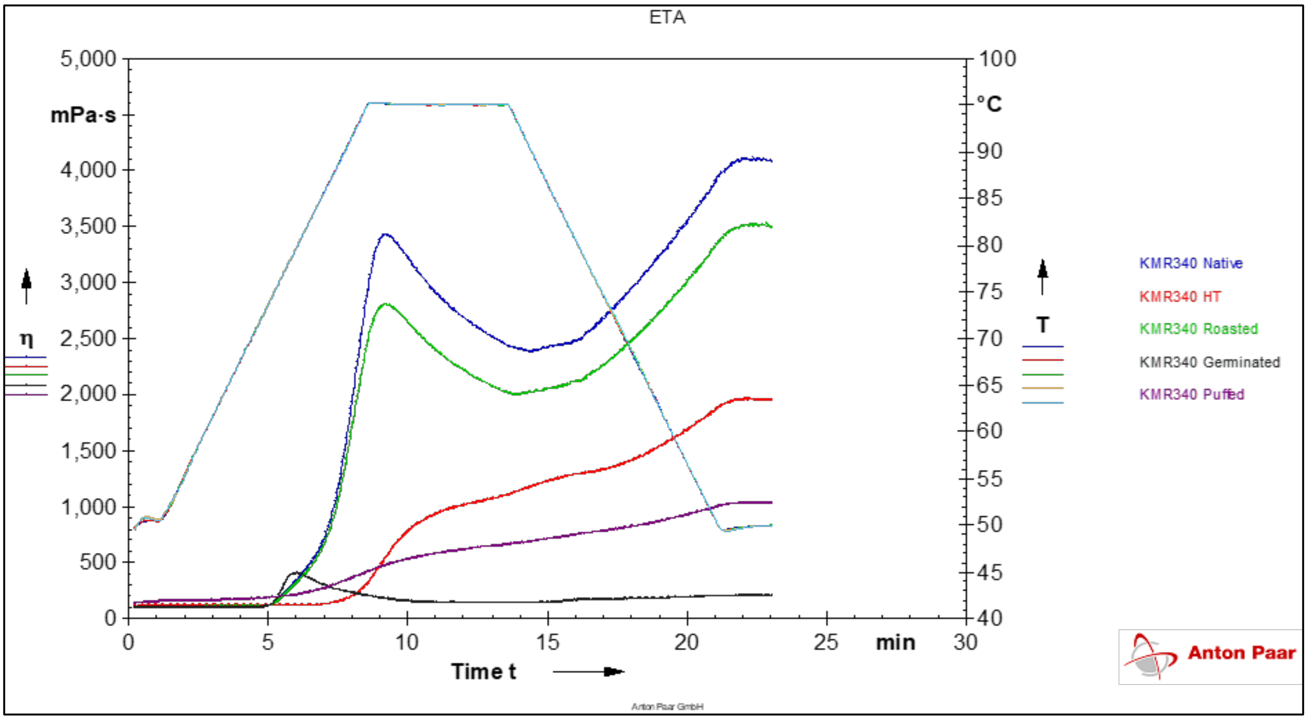

Fig 3b: RVA Patterns of milky cream finger millet flour

Table 1a: Effect of pre-treatments on proximate composition of finger millet flours

Treatment	Moisture (%wb)		Carbohydrates (%)		Protein (%)		Fat (%)	
	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340
N_f	12.53±0.07b	12.42±0.18b	74.95±0.58d	70.64±0.2f	6.53±0.06e	9.72±0.06b	1.57±0.05b	2.57±0.05a
Hf	12.00±0.00b	12.00±0.00b	76.2±0.26c	72.54±0.42e	6.08±0.18f	9.16±0.16c	1.58±0.05b	2.56±0.07a
Rf	10.70±0.11c	7.56±0.07d	78.13±0.24b	72.44±0.14e	6.11±0.18e	9.16±0.07c	1.57±0.03b	2.56±0.06a
Gf	13.62±0.28a	13.47±0.35a	70.5±0.69f	68.17±0.09g	7.51±0.08d	10.52±0.06a	1.17±0.05c	1.10±0.03d
Pf	4.83±0.17e	3.27±0.18f	81.26±0.26a	77.12±0.3bc	5.84±0.06f	6.65±0.09e	1.58±0.07b	2.58±0.06a

N_f: Native flour, H_f: hydrothermally treated flour, R_f: Roasted flour, Gf: flour from germinated grains, Pf: flour from puffed grains
The mean±standard deviation, n =3. Values with different superscripts differ significantly (p<0.05).

Table 1b: Effect of pre-treatments on proximate composition of finger millet flours

Treatment	Fiber (%)		Ash (%)		Iron (mg/100g)		Calcium (mg/100g)	
	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340
Nf	2.55±0.06d	2.86±0.08c	2.19±0.02b	1.15±0.10e	3.65±0.08h	4.69±0.10f	258.48±3.37c	295.82±8.54b
Hf	3.23±0.04b	3.19±0.03b	2.35±0.04a	1.21±0.02e	3.23±0.04i	4.46±0.04g	256.3±3.04c	290.08±2.37b
Rf	2.73±0.04c	2.83±0.04c	2.48±0.04a	1.36±0.05d	4.99±0.09e	5.49±0.03c	252.99±4.11c	292.36±2.36b
Gf	4.88±0.05a	4.99±0.09a	1.84±0.08c	0.96±0.06f	5.29±0.11d	6.11±0.02a	292.81±4.56b	313.56±5.25a
Pf	2.03±0.07e	2.07±0.06e	1.93±0.04c	1.09±0.03ef	4.55±0.07fg	5.69±0.06b	254.88±5.75c	287.78±3.97b

Nf: Native flour, Hf: hydrothermally treated flour, Rf: Roasted flour, Gf: flour from germinated grains, Pf: flour from puffed grains
The Mean ± Standard deviation, N=3. Values with different superscripts differ significantly (p<0.05)

Table 2: Effect of pre-treatments on physical properties of finger millet

Treatment	Bulk Density (kg/m³)		True Density (kg/m³)		Porosity (%)	
	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340
Nf	776.55±4.64b	747.55±6.36c	1278.87±20.03cd	1324.38±13.67bc	37.39±0.93ef	33.14±0.58f
Hf	729.72±2.27cd	739.41±2.09c	1362.98±12.66ab	1417.23±27.65a	44.72±2.95bc	40.76±1.06cde
Rf	794.39±10.56ab	809.29±2.28a	1299.10±50.71bcd	1326.65±22.08bc	38.85±1.60de	38.99±0.89de
Gf	717.89±13.85de	702.07±7.32e	1226.62±15.78d	1268.97±26.40cd	42.72±2.56bcd	47.41±1.69b
Pf	296.26±5.26g	437.03±2.78f	881.85±10.31f	1125.80±30.84e	60.31±1.39a	61.64±1.05a

Nf: Native flour, Hf: hydrothermally treated flour, Rf: Roasted flour, Gf: flour from germinated grains, Pf: flour from puffed grains
The Mean ± Standard deviation, N=3. Values with different superscripts differ significantly (p<0.05).

Table 3: Effect of pre-treatments on functional properties of finger millet flours

Treatment	Tap Density (kg/m³)		OAC (mL/g)		WAC (mL/g)		Swelling Power (g/g)		Dispersibility (%)	
	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340
Nf	958.66±36.25a	963.83±20.66a	1.77±0.03d	1.88±0.02bcd	2.21±0.03ef	2.25±0.02ef	10.98±0.26a	9.17±13.13b	79±0a	79±0a
Hf	919.78±15.00abc	889.83±3.78bc	1.80±0.06cd	1.90±0.02bcd	2.87±0.02c	2.44±0.07d	7.14±0.05d	6.04±0.12e	75±0c	75±0c
Rf	944.48±9.42ab	911.48±5.62abc	1.72±0.09d	1.83±0.01cd	2.28±0.00def	2.33±0.01de	10.76.53±0.45a	8.99±0.47b	78±0ab	78±0b
Gf	882.76±7.85c	934.15±3.12abc	1.98±0.08bc	1.97±0.14bc	2.14±0.02f	2.13±0.01f	4.21±0.29g	4.91±0.48 f	79±0a	78±0b
Pf	570.98±4.44e	712.66±34.43d	2.42±0.09a	2.03±0.02b	4.51±0.1b	5.46±0.13a	7.94±0.15c	6.12±0.06e	43±0e	48±0d

Nf: Native flour, Hf: hydrothermally treated flour, Rf: Roasted flour, Gf: flour from germinated grains, Pf: flour from puffed grains

The Mean ± Standard deviation, n =3, Values with different superscripts differ significantly (p<0.05)

Table 4: Effect of pre-treatments on Least Gel Concentration of finger millet flours

Treatments	2%		4%		6%		8%		10%		12%	
	MR-6	KMR-340	MR-6	KMR-340	MR-6	KMR-340	MR-6	KMR-340	MR-6	KMR-340	MR-6	KMR-340
Nf	-	-	-	-	-	-	±	±	+	+	+	+
Hf	-	-	-	±	±	+	-	+	+	+	+	+
Rf	-	-	-	-	-	-	-	-	±	±	+	+
Gf	-	-	-	-	-	±	±	+	+	+	+	+
Pf	-	-	-	-	±	-	+	±	+	+	+	+

Nf: Native flour, Hf: hydrothermally treated flour, Rf: Roasted flour, Gf: flour from germinated grains, Pf: flour from puffed grains -: Not gelled, ±:Gelled slightly, +:Gelled completely

Table 5: Effect of pre-treatments on RVA of finger millet flours

Treatment	Peak Time (min)		Peak Viscosity (MPA.S)		Peak Temperature (ºC)		Holding strength (MPA.S)		Break down Viscosity (MPA.S)		Final Viscosity (MPA.S)		Setback from peak (MPA.S)		Setback from trough (MPA.S)	
	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340	MR-1	KMR-340
Nf	8.533	8.533	2973	2878	72.72	72.90	1781	1445	1192	1434	4251	4072	1278	1194	2470	2628
Hf	8.533	8.533	592.5	305.3	71.85	67.00	279.3	165.6	313.1	139.6	2782	1948	2189	1643	2502	1783
Rf	8.533	8.533	2905	2431	72.68	73.66	1880	1284	1029	1147	4015	3505	1106	1074	2135	2222
Gf	5.653	6.017	445.2	408.8	72.08	73.69	130.6	138.9	314.6	269.9	177.4	207.5	267.8	201.3	46.84	68.59
Pf	8.533	8.533	676.3	414.9	74.49	68.60	641.7	334.2	34.58	80.76	1632	1031	955.3	615.8	989.9	696.6

Nf: Native flour, Hf: hydrothermally treated flour, Rf: Roasted flour, Gf: flour from germinated grains, Pf: flour from puffed grains

Conclusion

The current study underscores the significant impact of pre-treatments, specifically roasting and germination on various aspects such as proximate composition, mineral content, functional properties, pasting characteristics and rheological attributes of flours derived from two differently coloured varieties of finger millet (MR1 and KMR-340). Notably, roasting demonstrated notable benefits, leading to increased iron content and enhanced functional properties. Popping and hydrothermal processing were also found to augment the carbohydrate profile of finger millet with popping additionally contributing to higher iron content. Furthermore, germination emerged as a valuable pre-treatment method elevating protein and calcium content while improving pasting properties compared to native finger millet. Importantly, these findings suggest that pre-treatments open avenues for diversifying finger millet products. The outcomes of this research can serve as a valuable resource for industrial machinery design besides, facilitating the development of gluten-free products and snacks with enhanced nutritional profiles. Given the health-promoting nutrient composition of finger millet, it stands out as an ideal candidate for food fortification initiatives aimed at combatting micronutrient deficiencies. Flour from buff coloured variety was found nutritionally superior and can be used for substitution at much higher levels in conventional foods without impacting the appearance attributes.

References

1. Amadou I, Mahamadou EG, Le GW. Millets, Nutritional composition, some health benefits and processing - A Review. Food Science and Technology. 2013;25(7):501-508.
2. AOAC. Association of Official Analytical Chemists (AOAC) Official Methods of Analysis of AOAC International. AOAC International. https://www.aoac.org/official-methods-of-analysis-21st-edition-2019.
3. Choudhury M, Das P, Baroova B. Nutritional evaluation of popped and malted indigenous millet of Assam. J Food Sci. Technol. 2011;48(6):706-711.
4. Das R, Pandravada SR, Harikrishnan PJ. Estimation of grain nutrient and their association with grain yield in finger millet [*Eleusine coracana* (l.) Gaertn]. Plant Archives. 2017;17(1):241-6.
5. Dharmaraj U, Malleshi NG. Changes in carbohydrates, proteins and lipids of finger millet after hydrothermal processing. LWT-food Science and Technology. 2011;44(7):1636-1642.
6. Dharmaraj U, Ravi R, Malleshi NG. Physicochemical and textural characteristics of expanded finger millet. International Journal of Food Properties. 2012;15(2):336-349.
7. Dharmaraj U, Parameswara P, Somashekar R, Malleshi NG. Effect of processing on the microstructure of finger millet by x-ray diffraction and scanning electron microscopy. J Food Sci. Technol. 2014;51:494-502.
8. Dharmaraj U, Meera, MS, Yella Reddy SY, Malleshi NG. Influence of hydrothermal processing on functional properties and grain morphology of finger millet. J Food Sci. Technol. 2015;52(3):1361-1371.
9. Elkhalifa AEO, Bernhardt R. Influence of grain germination on functional properties of sorghum flour. Food Chemistry, 2010;121(2):387-392.
10. Faleye T, Atere AO, Oladipo ON, Agaja MO. Determination of some physical and mechanical properties of some cowpea varieties. African Journal of Agricultural Research 2013;8(49):6485-6487.
11. Gowda NN, Siliveru K, Prasad PV, Bhatt Y, Netravati BP. Gurikar C. Modern processing of Indian millets: A perspective on changes in nutritional properties. Foods. 2022;11(4):499.
12. Hassan ZM, Sebola NA, Mabelebele M. The nutritional use of millet grain for food and feed: A review. Agriculture and Food Security, 2021;10(1):1-14.
13. Kaur M, Kaushal P, Sandhu KS. Studies on physicochemical and pasting properties of Taro (*Colocasia esculenta* L.) flour in comparison with a cereal, tuber and legume flour. J Food Sci. Technol. 2013;50:94-00.
14. Kaur H., Oberoi HK, Ganapathy KN, Bhardwaj R. Effect of popping and malting processing techniques on physiochemical, antinutrients and antioxidant properties of millets flour. J Food Sci. Technol, 2023, 1-15.
15. Kumar Y, Sharanagat VS, Singh L, Mani S. Effect of germination and roasting on the proximate composition, total phenolics, and functional properties of black chickpea (*Cicer arietinum*). Legume Science. 2019;2(1):1-7
16. Kumar P, Kaur C, Sethi S, Jambh H. Effect of extruded finger millet on dough rheology and functional quality of pearl millet-based unleavened flatbread. Cereal Chemistry. 2020;97(5):991-998
17. Malleshi NG, Desikachar, HSR. Varietal differences in puffing quality of ragi (*Eleusine coracana*). J Food Sci. Technol 1981;18(1):30-32.
18. Mirza N, Sharma N, Srivastava S, Kumar A. Variation in popping quality related to physical, biochemical and nutritional properties of finger millet genotypes. Proceedings of The National Academy of Sciences, India Section B:Biological Sciences 2015;85:507-515.
19. Mishra G, Joshi DC, Panda BK. Popping and puffing of cereal grains: A review. Journal of grain processing and storage. 2014;1(2):34-46.
20. Mudau M, Ramashia SE. Mashau ME. Mineral content, functional, thermo-pasting, and microstructural properties of spontaneously fermented finger Millet Flours. Foods 2022;11(16):2474.
21. Najdi Hejazi S, Orsat V. Optimization of the malting process for nutritional improvement of finger millet and amaranth flours in the infant weaning food industry. International Journal of Food Sciences and Nutrition 2017; *68*(4):429-441.
22. Nakarani UM, Singh D, Suthar KP, Karmakar N, Faldu P, Patil HE. Nutritional and phytochemical profiling of nutracereal finger millet (*Eleusine coracana L.*) genotypes. Food Chemistry 2021;341:128271.
23. Navyashree N, Sengar AS, Sunil CK, Venkatachalapathy N. White Finger Millet (KMR-340): A comparative study to determine the effect of processing and their characterisation. Food Chemistry. 2022;374:131665.
24. Nefale FE, Mashau ME. Effect of germination period on the physicochemical, functional and sensory properties of finger millet flour and porridge. Asian Journal of Applied Sciences, 2018;6(5):360-367.
25. Obadina A, Ishola IO, Adekoya IO, Soares AG, de Carvalho CW, Barboza HT. Nutritional and physico-chemical properties of flour from native and roasted whole grain pearl millet (*Pennisetum glaucum* [L.] R. Br.). Journal of Cereal Science 2016;70:247-252.
26. Pawar PP, Sawate AR, Kshirsagar RB, Agarkar BS. Studies on physicochemical properties of finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*). Pharma Innovation, 2020; 9(2):5-8.
27. Platel K, Eipeson SW, Srinivasan K. Bioaccessible mineral content of malted finger millet (*Eleusine coracana*), wheat (*Triticum aestivum*), and barley (*Hordeum vulgare*). Journal of Agricultural and Food Chemistry 2010;58(13):8100-8103.
28. Powar RV, Aware VV, Shahare PU, Sonawane SP,

Dhande KG. Moisture Dependent Physical Properties of Finger Millet Grain and Kernel (*Eleusine coracana* (L.) Gaertn) The Journal of the Indian Society of Coastal Agricultural Research 2018;36(1):48-56.
29. Rajasekar M, Edukondalu L, Smith DD, Veeraprasad G. Changes in Engineering Properties of Finger Millet (PPR-2700, Vakula) on Hydrothermal Treatment. The Andhra Agricutlural Journal 2018;65(2):420-429.
30. Ramashia SE, Gwata ET, Meddows-Taylor S, Anyasi TA, Jideani, AIO. Some physical and functional properties of finger millet (*Eleusine coracana*) obtained in sub-Saharan Africa. Food Res. Int. 2017;104, 110-118.
31. Rao SR, Juliano BO. Effect of parboiling on some physicochemical properties of rice. Journal of Agricultural and Food Chemistry 1970; 18(2):289-294.
32. Ravishankar CR, Shubhashree KS, Raveendra HR, Shobha D. A new revolution in finger millet breeding-white grained variety KMR-340. 2019;11(7):8264-8267.
33. Saini S, Saxena S, Samtiya M, Puniya M, Dhewa T. Potential of underutilized millets as Nutri-cereal:an overview. J Food Sci. Technol 2021;58(12):4465-4477.
34. Sangamithra A, Swamy GJ, Sorna PR, Nandini K, Kannan K, Sasikala S, *et al.* Moisture dependent physical properties of maize kernels. International Food Research Journal 2016; 23(1):109-115.
35. Sasaki T, Matsuki J. Effect of Wheat Starch Structure on Swelling Power. Cereal Chem 1998;75 (4):525-529.
36. Sharanagat VS, Suhag R, Anand P, Deswal G, Kumar R, Chaudhary A, *et al.* Physico-functional, thermo-pasting and antioxidant properties of microwave roasted sorghum [*Sorghum bicolor* (L.) Moench]. Journal of Cereal Science, 2019;85:111-119.
37. Shiihii SU, Musa H, Bhati PG, Martins E. Evaluation of physicochemical properties of *Eleusine coracana* starch. Niger. J. Pharma. Sci 2011; 10(1):91-102.
38. Shingare SP, Thorat BN. Effect of drying temperature and pre-treatment on protein content and color changes during fluidized bed drying of finger millets (Ragi, *Eleusine coracana*) sprouts. Dry. Technol. 2013;31(5): 507-518.
39. Singh KP, Potdar RR, Agrawal KN, Tiwari PS, Hota S. Effect of moisture content on physical properties of finger (*Eleusine coracana*) millet. AMA 2017;48(4):24-32.
40. Tiwari A, Jha SK, Pal RK, Sethi S, Krishan L. Effect of pre-milling treatments on storage stability of pearl millet flour. J Food Process. Preserv 2014;38(3):1215-1223.
41. Vadivoo AS, Joseph R, Ganesan NM. Genetic variability and diversity forprotein and calcium contents in finger millet [*Eleusine coracana* (L.) Gaertn] in relation to grains color. Plant Foods for Hum. Nutr. 1998;52:353-364.
42. Yenasew A. Urga K. Effect of the germination period on functional properties of finger millet flour and sensorial quality of porridge. Food Science and Nutrition 2023;11(5):2336-2343.
43. Yousaf L, Hou D, Liaqat H, Shen Q. Millet:A review of its nutritional and functional changes during processing. Food Res. Int. 2021;142, 110197.
44. Zhiqiang L, Xiao-su Y. Yi F. Effect of bound water on thermal behaviors of native starch, amylose and amylopectin. Starch-Stärke. 1999;51(11-12):406-410.