DR-2429
[1-7]

RESEARCH ARTICLE Asian Journal of Dairy and Food Research

Effect of Soaking, Roasting and Germination on Nutritional Composition, Colour Characteristics and Functional Properties of Amaranth Seed Flour

Monali Mohanrao Joshi [1], Vijaya S. Pawar[1], Godawari S. Pawar[2], Kishor K. Anerao[3], Aditi H. Bachate[1], Shradha M. Rodge[4], Sachin A. Giri[5]

10.18805/ajdfr.DR-2429

ABSTRACT

Background: Amaranth is a fast-growing, gluten-free pseudo-cereal notable for its high protein, dietary fiber, healthy fats and essential minerals. This study aimed to investigate the impact of various pretreatments on the nutritional composition, antinutritional components, colour and functional attributes of amaranth flour.

Methods: Amaranth grains underwent soaking, roasting and germination treatments. The resulting flours were analysed for proximate composition, mineral content, antinutritional factors, colour characteristics and functional properties.

Result: Pretreatments significantly affected amaranth flour composition. Soaking slightly increased protein (16.63%) and carbohydrates (62.17%) while reducing moisture, fat, fiber and ash. Roasting raised carbohydrates (69.5%) but decreased other nutrients, whereas germination enhanced protein (17.62%) and fiber (6.39%) with moderate moisture. Minerals such as Ca, K, Mg, Fe and Zn were highest in germinated flour, while P, Fe and Zn increased with roasting. All treatments reduced tannins and phytic acid, with germination being most effective. Soaking increased lightness (L*), roasting increased redness (a*) and yellowness (b*) and both roasting and germination improved functional properties water absorption, solubility and oil absorption while lowering bulk density. Germination proved to be the most effective pretreatment, as it improved nutritional content, decreased antinutritional factors and enhanced functional properties, highlighting its suitability for producing nutrient-dense amaranth flour for various food uses.

Key words: Amaranth, Antinutritional factors, Colour, Functional properties, Pretreatments, Proximate composition.

INTRODUCATION

Ensuring global food security in the future requires the identification and sustainable utilization of resilient plant-based resources. Grain amaranth (*Amaranthus spp*.) represents one such overlooked and underexploited crop with strong adaptability to drought and considerable nutritional potential that remains insufficiently studied (Akin-Idowu *et al*., 2017). The seeds contain a high-quality protein content ranging from 13-19%, with a well-balanced amino acid profile and notably high levels of lysine an essential amino acid that is typically limited in most cereal grains (Amare *et al*., 2015). The protein composition of amaranth is reported to closely align with the amino acid recommendations set by FAO/WHO due to its desirable nutritional balance (Murya and Pratibha, 2018).

In terms of mineral composition, grain amaranth exhibits levels comparable to widely consumed cereals such as sorghum, millet, wheat, rice and maize (Mustafa *et al*., 2011). Additionally, it contains beneficial lipids, carbohydrates, antioxidants and various bioactive substances associated with positive health outcomes (Karamac *et al*., 2019). Unlike conventional cereal grains especially wheat, amaranth holds promise as a gluten-free ingredient for formulating foods suitable for individuals with celiac disease (Martinez-Villaluenga *et al*., 2020). Although antinutritional factors in amaranth can restrict its direct use, pretreatments such as soaking, roasting and

[1]Department of Food Process Technology, College of Food Technology, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani-431 402, Maharashtra, India.
[2]Department of Agricultural Botany, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani-431 402, Maharashtra, India.
[3]Department of Food Microbiology and safety, College of Food Technology, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani-431 402, Maharashtra, India.
[4]College of Food Technology, Krishi Vigyan Sankul, Kashti, Malegaon, Mahatma Phule Krishi Vidyapeeth, Rahuri-423105, Maharashtra, India.
[5]Department of Food Engineering, College of Food Technology, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani-431 402, Maharashtra, India.

Corresponding Author: Monali Mohanrao Joshi, Department of Food Process Technology, College of Food Technology, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani-431 402, Maharashtra, India. Email: monalij700@gmail.com
ORCID: 0009-0004-4572-0746

How to cite this article: Joshi, M.M., Pawar, V.S., Pawar, G.S., Anerao, K.K., Bachate, A.H., Rodge, S.M. and Giri, S.A. (2026). Effect of Soaking, Roasting and Germination on Nutritional Composition, Colour Characteristics and Functional Properties of Amaranth Seed Flour. *Asian Journal of Dairy and Food Research.* 1-7. doi: 10.18805/ajdfr.DR-2429.

Submitted: 04-12-2025 **Accepted:** 17-02-2026 **Online:** 03-03-2026

germination help reduce these compounds, making the grain more suitable for consumption. Evaluating its functional properties is therefore important for its incorporation into diverse food systems and processing technologies (Teresa and Pag, 2021). Amaranth is a small-seeded grain rich in nutrients and phytochemicals, offering several health benefits and protection against chronic diseases such as hypertension, diabetes, cancer and cardiovascular disorders. Despite these advantages, it has declined in popularity due to its coarse nature and is underutilised in developed regions. Recent research efforts aim to reintroduce and valorise this grain for modern food applications (Bhat *et al*., 2018; Jan *et al*., 2023).

Hence, the present research was conducted to assess effect of different pretreatments namely soaking, roasting and germination on the proximate composition, mineral profile, antinutrient content, colour characteristics and functional properties of amaranth seed flour. The findings aim to support its potential application in the development of diverse value-added food products.

MATERIALS AND METHODS

Materials

The present study took place during 2024-2025 at the "College of Food Technology, Vasantrao naik Marathwada Krishi Vidyapeeth (VNMKV), Parbhani." Amaranth seed grains, purchased from local market of Parbhani and cleaned to remove unwanted materials. Four batches were made 250 g each portion for three pretreatments (soaking, roasting and germination) and one used as a raw sample.

Sample preparation and pretreatments

Untreated amaranth seed flour

Amaranth seeds were cleaned and then milled through lab scale hammer mill to get fine flour of 70 mesh size. The untreated amaranth seed flour was stored in polyethylene zipper plastic bag at room temperature.

Soaked amaranth seed flour

Soaking treatment for amaranth seeds was carried out with slight modifications to the procedure described by Thakur *et al*. (2021). The grains were washed and soaked in distilled water (1:5 ratio) for 12 h. After soaking, they were dried at 65°C for 4 h, cooled to room temperature and ground into flour. The flour was then sieved through a 70-mesh screen, packed in polyethylene zipper bags and stored at room temperature for further analysis.

Roasted amaranth seed flour

Roasting was conducted with slight modifications to the method reported by Shinde (2023). Cleaned amaranth grains were roasted in an oven at 120°C for 10 min, then cooled to room temperature. They were ground into flour and sieved through a 70-mesh screen. The flour was packed in polyethylene zipper bags and stored at room temperature for later use and analysis.

Germinated amaranth seed flour

The germination method was followed with slight changes based on Thakur *et al*. (2021). Cleaned grains (250 g) were soaked in 1000 mL of water for 8 h in a muslin-covered beaker under dark at room-temperature. After draining the water, the grains were wrapped in a moist muslin cloth and allowed to germinate for 72 h, with occasional sprinkling of water to keep them moist. Once germination was complete, the grains were dried in a cabinet dryer at 60°C for 4 h, cooled, ground into flour, sieved through a 70-mesh screen and packed in polyethylene zipper bags for later analysis.

Proximate composition

The proximate composition of both untreated and pretreated amaranth seed flour samples was assessed to determine moisture, fat, protein, crude fiber, ash and carbohydrate content. All analyses were carried out following the standard procedures described by AOAC (2005).

Mineral composition

Mineral content of the samples was evaluated using the analytical methods described by AOAC (2005). The minerals quantified included calcium, phosphorus, iron, magnesium, potassium, zinc, manganese and copper.

Antinutritional factor

Tannin and phytate was determined as per the method suggested by (Mane *et al*., 2023). For tannin estimation, about 0.1 ml of sample extract was transferred to a 100 ml volumetric flask containing 75 ml of distilled water. Folin-Denis reagent (5 ml) and sodium carbonate solution (10 ml) were then added and the volume was adjusted to 100 ml with distilled water. The concentration of tannic acid used was 0.1 mg/ml. The resulting solution was incubated for 30 min and then the absorbance was recorded against an experimental blank at 760 nm. The data was expressed as milligram tannic acid equivalent/100 g dry basis of flour weight (mg TAE/100 g).

For the phytate test, the powder sample (0.15 g) was combined with 10 ml of HCl (2.4%) and the extraction was performed using a shaking incubator (1 h /25-27°C). The resulting solution was centrifuged (3000 rpm/30 min) and filtered to obtain a pure phytate extract. Briefly, 1 ml of wade reagent (0.3% of sulfosalicylic and 0.03% $FeCl_3.6H_2O$ acid in water) was mixed with sample extract (3 ml) and vortexed for 5 s. The concentration of phytic acid used was 1 mg/ml. The reading was immediately recorded at a wavelength of 500 nm and the results reported as mg/100 g dry basis of sample weight.

Colour analysis

The colour attributes of untreated and treated amaranth flour were measured using a Hunter Lab Colorimeter (Color Flex EZ). The device was calibrated with a white tile before use and L*, a* and b* values were recorded. Mean readings from three replicates were reported for each sample (Bachate *et al*., 2025).

Functional properties

Determination of water absorption capacity

The water absorption capacity of untreated and pretreated (soaked, roasted and germinated) amaranth flours was determined following Joshi *et al*. (2022). 1 g of flour was mixed with 10 mL of distilled water, equilibrated for 30 min at 30±2°C, centrifuged at 3000 rpm for 30 min and expressed as the percentage of water retained per gram of flour.

Water solubility index (WSI)

The water solubility index of untreated and pretreated (soaked, roasted and germinated) amaranth flour was evaluated following the procedure of Joshi *et al*. (2022), with slight modifications. 1 g of flour was mixed with 10 mL of water, incubated at 37°C for 30 min and centrifuged at 3000 rpm for 15 min. The supernatant was transferred to a pre-weighed dish and dried at 110°C to constant weight and the residue was used to calculate the water solubility index.

$$\text{WAC}\left(\frac{g}{g}\right) = \frac{\text{Weight of sediment}}{\text{Weight of flour sample}}$$

$$\text{WSI}\left(\frac{g}{100\ g}\right) = \frac{\text{Weight of dissolved solids in supernatant}}{\text{Weight of flour sample}} \times 100$$

Bulk Density

Bulk density was measured by filling 100 g of flour into a 250 mL graduated cylinder, tapping gently until constant volume and calculating density from the final volume and weight (Joshi *et al*., 2022).

$$\text{Bulk density}\left(\frac{g}{ml}\right) = \frac{\text{Mass of sample}}{\text{Volume of sample}}$$

Oil absorption capacity

The oil absorption capacity of flour was determined as per Singh and Punia (2020). One gram of flour was mixed with 10 mL hydrogenated fat, centrifuged at 2000 rpm for 30 min, excess fat removed and the sample weighed. Oil absorption was calculated as the percentage of fat retained relative to the flour's initial weight.

Statistical analysis

Data were analysed using a completely randomized design (CRD) and treatment differences were tested through ANOVA as per Panse and Shukhatame (1985).

RESULTS AND DISCUSSION

Proximate composition

The effect of different pretreatments like soaking, roasting and germination on proximate composition of amaranth seed flour was presented in Table 1. Moisture content decreased in all pretreated amaranth flours compared to raw flour. Soaked and germinated samples showed 8.7% and 8.1% moisture, respectively, due to drying after treatment, while roasting caused the largest reduction from 10.2% to 6.6%, likely from heat-induced removal of free and bound water (Komi *et al*., 2008).

A noticeable decline in fat content was observed in the treated samples compared with the untreated amaranth flour, which initially contained 4.95% fat. The soaked amaranth flour showed a similar fat content to the raw flour, measuring 4.91%. Roasting led to a reduction, with roasted flour containing 3.65% fat. The germinated flour demonstrated the most significant decrease, with the fat level dropping to 2.59%. During germination, the decline in fat content occurs because stored fats are used to supply energy for seed sprouting (Sade, 2009). The reduction is also linked to the enhanced action of lipolytic enzymes, which break down fats to support the metabolic activities essential for seed growth (Beniwal *et al*., 2019).

Protein content increased after soaking (16.63%) and germination (17.62%) but decreased with roasting (15.42%), likely due to amino acid formation during germination and heat-induced protein denaturation during roasting. However, roasting led to a reduction in protein content, possibly due to structural alterations in native proteins caused by heat treatment (Fasasi, 2009).

Crude fiber was highest in germinated flour (6.39%) and lowest in roasted flour (2.58%). Thakur *et al*. (2021) observed significant increases in protein and crude fiber following germination, confirming that sprouting enhances nutrient contents by activating endogenous enzymes. while ash remained relatively stable (2.25-2.45%). Carbohydrates increased in all treated samples, with the highest in roasted flour (69.50%) and germinated flour (63.04%), compared to raw flour (60.69%). Comparable increases in carbohydrate fractions following soaking and germination have also been documented by Thakur *et al*. (2021), who reported gains in digestible carbohydrates with reduced antinutrients during processing. These results align with previous reports on processed amaranth flour (Bachate *et al*., 2025).

Mineral composition

The effect of different pretreatments soaking, roasting and germination on mineral composition of amaranth seeds was assessed and the results are depicted in Table 2.

Germination resulted in the highest calcium level (79.64 mg/100 g), exceeding that of the untreated seeds (74.28 mg/100 g). A minor reduction in calcium was observed after soaking (73.98 mg/100 g), while roasted flour showed a similar value to the control (74.06 mg/100 g).

Phosphorus content in raw amaranth flour measured 528.6 mg/100 g and exhibited a slight increase after germination (557.3 mg/100 g). Roasting also enhanced phosphorus content to 556.2 mg/100 g, whereas soaking resulted in a marginal decrease to 527.4 mg/100 g. Magnesium levels decreased in soaked (253 mg/100 g) and roasted samples (240 mg/100 g). However, germination

improved magnesium content to 299 mg/100 g compared to the untreated sample (261 mg/100 g).

The potassium concentration was highest in germinated amaranth flour (554.6 mg/100 g), followed by roasted flour (533.1 mg/100 g), while the untreated seeds contained 508.2 mg/100 g. A slight reduction was recorded in soaked flour, which measured 507.9 mg/100 g. Iron content also showed variation across treatments, with a small decrease observed in soaked samples (13.24 mg/100 g) compared to the control (13.95 mg/100 g). In contrast, roasting and germination enhanced iron levels to 16.01 mg/100 g and 16.87 mg/100 g, respectively.

Zinc content increased after roasting and germination, reaching 5.72 and 5.88 mg/100 g, while untreated and soaked samples had 4.12 and 4.03 mg/100 g, respectively. Manganese ranged from 2.90 mg/100 g in soaked flour to 3.27 mg/100 g in germinated flour, with untreated and roasted samples at 3.18 and 3.22 mg/100 g. Copper also improved with processing, measuring 0.93, 0.88 and 1.32 mg/100 g in soaked, roasted and germinated flours, compared to 0.82 mg/100 g in the untreated sample.

Soaking reduced minerals content as some minerals solubilized into the water (Chavan *et al*., 2013). Germination showed the highest mineral increase due to enzyme activity, nutrient release and breakdown of antinutrients like tannins and phytates (Khan *et al*., 2013). The results are consistent with previous studies showing increased mineral content in processed amaranth. Thakur *et al*. (2021) reported iron and zinc contents of 16.2 mg/100 g and 5.6 mg/100 g, respectively, in germinated amaranth, attributing the rise to phytate degradation. Similarly, Shinde (2023) observed higher calcium and magnesium levels after germination. In line with these findings, germinated amaranth flour in this study exhibited the highest mineral concentrations (Table 2), confirming that pretreatments effectively enhance mineral content and potential bioavailability.

Antinutritional factors

Anti-nutrients like tannins and phytic acid were analysed for amaranth seed flours (Table 3). Processing of amaranth seed flours i.e., soaking, roasting and germination caused decrease in phytic acid content 1.42% to 1.27%, 0.79% and 0.78% respectively and tannin 0.120% to 0.093%, 0.051% and 0.048% respectively.

The decrease in tannin and phytic acid content during soaking may be attributed to their decline into the soaking water, while during germination, enzymatic activity plays a major role. In the case of phytic acid, soaking increases the activity of natural enzymes such as phytases, which break down phytic acid into lower inositol phosphates and free inorganic phosphate (Larsson and Sandberg, 1992). The present results are similar with those reported by Singh *et al*. (2017).

Colour analysis

The colour of amaranth flour was evaluated after soaking, roasting and germination by measuring *L** (lightness), *a**

Table 1: Effect of different pretreatments on proximate composition of amaranth.

Nutrients (%)	Content (%)			
	Untreated amaranth flour	Soaked amaranth flour	Roasted amaranth flour	Germinated amaranth flour
Moisture	10.20±0.14	8.7±0.10	6.6±0.12	8.1±0.06
Fat	4.95±0.18	4.91±0.10	3.65±0.21	2.59±0.26
Protein	16.40±0.15	16.63±0.12	15.42±0.23	17.62±0.14
Crude fiber	5.31±0.13	5.19±0.17	2.58±0.19	6.39±0.18
Ash	2.45±0.11	2.40±0.08	2.25±0.07	2.26±0.15
Carbohydrate	60.69±0.50	62.17±0.49	69.50±0.46	63.04±0.42

*Each value is mean of three determinations.

Table 2: Effect of different pretreatments on mineral composition of amaranth

Minerals	Content (mg/100 g)			
	Untreated amaranth flour	Soaked amaranth flour	Roasted amaranth flour	Germinated amaranth flour
Calcium	74.28±0.58	73.98±0.23	74.06±0.29	79.64±0.25
Phosphorus	528.6±0.62	527.4±0.65	556.2±0.43	557.3±0.38
magnesium	261±0.45	253±0.31	240±0.16	299±0.10
Potassium	508.2±0.28	507.9±0.25	533.1±0.50	554.6±0.27
Iron	13.95±0.17	13.24±0.15	16.01±0.22	16.87±0.31
Zinc	4.12±0.09	4.03±0.19	5.72±0.23	5.88±0.26
Manganese	3.18±0.10	2.90±0.13	3.22±0.12	3.27±0.15
Copper	0.82±0.06	0.93±0.09	0.88±0.07	1.34±0.10

*Each value is mean of three determinations.

(red–green) and *b** (yellow–blue) values, as presented in Table 4. *L** ranges from 0 (black) to 100 (white), with positive *a** indicating redness and negative *a** greenness, while positive *b** represents yellowness and negative b* blueness. The untreated seeds had *L*, a* and b** values of 64.17, 7.80 and 31.56, whereas the untreated flour showed 77.71, 3.69 and 19.47.

Soaking treatment reported in an increase in *L** value of amaranth flour, recorded as 79.80. The *a** value was 3.18, while the *b** value was 18.53. The increase in *L** value shows the flour became lighter, while small decreases in *a** and *b** values indicate less red and yellow color. The lighter color may result from pigments and phenolic compounds leaching into the soaking water (Rao *et al*., 2013).

During roasting process *L** value of amaranth flour was indicated as 75.96, while *a** value was 5.95 and the *b** value was 25.10. The increase in *a** and *b** values recorded an enhancement in the redness and yellowness of the flour as the roasting temperature increased. The increase in *a** and *b** values and the decrease in *L** value reflect the reddish-yellow darkening of flour due to browning reactions like Maillard and caramelization during roasting, which form brown pigments (Bello *et al*., 2017).

Germination treatment also affects the colour values of amaranth flour, with *L** value 76.47, *a** value 3.64 and *b** value 22.17 after 72 h of germination. Germination slightly darkens flour (lower *L**) due to enzyme activity and phenolic formation, while redness and yellowness (*a** and *b**) increase from carotenoids and flavonoids in germinated seeds (Sogut and Seydim, 2018). Roasting produces the highest redness and yellowness, showing a stronger colour effect (Beniwal *et al*., 2019).

Functional properties

Functional properties are the characteristics of a substances that influence its performance and interaction with other components during food processing. They are commonly assessed through parameters such as water absorption capacity (WAC), water solubility index (WSI), oil absorption capacity (OAC) and bulk density (BD). The effects of soaking, roasting and germination on amaranth flour's functional properties are presented in Table 5.

WAC increased from 2.66 g/g in untreated flour to 2.83, 2.92 and 2.91 g/g in soaked, roasted and germinated samples, respectively. The higher WAC after roasting is likely due to heat-induced denaturation of proteins and structural changes in starch, exposing more water-binding sites (Singh and Singh, 2020). Germination enhances WAC through enzymatic breakdown of starch and proteins, producing more soluble molecules capable of retaining water (Maldonado-Cervantes *et al*., 2019), while soaking leads to a slight increase by softening and hydrating the grains (Olagunju and Ifesan, 2021).

Similarly, WSI rose with pretreatments, from 6 g/100 g in untreated flour to 8, 10 and 14 g/100 g in soaked, roasted and germinated samples, respectively. The pronounced increase during germination results from enzymatic hydrolysis of starch into dextrins and simple sugars, which improves solubility (Gamel *et al*., 2016). Roasting also elevated WSI, likely due to partial starch gelatinization and formation of Maillard reaction products (Mbithi-Mwikya *et al*., 2018), whereas soaking caused a noticeable increase, possibly due to leaching of soluble compounds.

Oil absorption capacity of amaranth flour increased with pretreatments, from 1.65 ml/g in untreated flour to 2.40 ml/g in roasted and 2.26 ml/g in germinated samples, while soaked flour showed a slight increase to 1.73 ml/g. The higher OAC after roasting is attributed to thermal protein denaturation, which exposes hydrophobic side chains that bind oil (Altan *et al*., 2009). Germination improves OAC by breaking down high molecular weight compounds and increasing porosity, enhancing oil retention. Structural changes, such as partial starch-protein

Table 3: Effect of different pretreatments on antinutritional factors of amaranth.

Antinutritional factors	Content (%)			
	Untreated amaranth flour	Soaked amaranth flour	Roasted amaranth flour	Germinated amaranth flour
Tannin	0.120±0.09	0.093±0.05	0.051±0.04	0.048±0.01
Phytic acid	1.42±0.12	1.27±0.13	0.79±0.13	0.78±0.10

*Each value is mean of three determinations.

Table 4: Effect of different pretreatments on colour analysis of amaranth seed flour.

Pretreatments	Values		
	L*	a*	b*
Raw amaranth seeds	64.17±0.38	7.80±0.10	31.56±0.60
Untreated amaranth seeds flour	77.71±0.29	3.69±0.18	19.47±0.26
Soaked amaranth flour	79.80±0.27	3.18±0.21	18.53±0.23
Roasted amaranth flour	75.96±0.22	5.95±0.32	25.10±0.19
Germinated amaranth flour	76.47±0.35	3.64±0.25	22.17±0.29

*Each value is mean of three determinations.

Table 5: Effect of different pretreatments on functional properties of amaranth flour.

Pretreatments	Functional properties			
	Water absorption capacity(g/g)	Water solubility index (g/100g)	Oil absorption capacity (ml/g)	Bulk density (g/ml)
Untreated amaranth flour	2.66±0.13	6±0.25	1.65±0.12	0.74±0.11
Soaked amaranth flour	2.83±0.11	8±0.27	1.73±0.09	0.67±0.05
Roasted amaranth flour	2.92±0.17	10±0.22	2.40±0.21	0.59±0.12
Germinated amaranth flour	2.91±0.21	14±0.18	2.26±0.17	0.60±0.10

*Each value is mean of three determinations.

breakdown and more porous microstructures, further facilitate oil absorption (Onwuka, 2005; Gao *et al*., 2014).

Bulk density decreased from 0.74 g/ml in untreated flour to 0.67, 0.59 and 0.60 g/ml in soaked, roasted and germinated samples, respectively. Roasting reduces density through puffing, lower particle compactness and increased porosity (Awolu *et al*., 2017), while germination softens polysaccharides, producing lighter, porous flour. Soaking caused only a slight decrease (Gamel *et al*., 2006). Overall, pretreatments enhanced functional properties by disrupting structure and increasing porosity, exposing hydrophilic and hydrophobic sites, which improve water and oil retention. These modifications make the flour suitable for bakery, protein-enriched snacks and beverage applications where hydration and oil binding are essential (Onwuka, 2005; Gao *et al*., 2014).

CONCLUSION

The findings of this study indicate that pretreatments such as soaking, roasting and germination enhanced the nutritional, mineral, colour and functional properties of amaranth flour, with germination proving the most effective. These treatments also reduced antinutritional factors, improving nutrient availability. This work demonstrates the strong potential for the commercial scale up, shelf-life enhancement and the use of combined pretreatments to further enhance flour quality.

ACKNOWLEDGEMENT

The authors extend their gratitude to Dr. V. S. Pawar, Research Guide, for continuous guidance and support.

Disclaimer

The views presented in this manuscript are those of the author, who is solely responsible for its content and accuracy.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

Akin-Idowu, P.E., Odunola, O.A., Gbadegesin, M.A., Ademoyegun, O.A., Aduloju, A.O and Olagunju, Y. O. (2017). Nutritional evaluation of five species of grain amaranth - An underutilized crop. *International Journal of Sciences.* **3(01):** 18-27.

Altan, A., McCarthy, K.L. and Maskan, M. (2009). Effect of extrusion process on nutritional properties of barley-based extrudates. *Journal of Food Engineering.* **90(2):** 291-297.

Amare, E., Mouquet-Rivier, C., Servent, A., Morel, G., Adish, A. and Haki, G.D. (2015). Protein quality of amaranth grains cultivated in Ethiopia as affected by popping and fermentation. *Food and Nutrition Sciences*. **06**(**01**)**:** 38-48.

AOAC, (2005). Official Methods of Analysis 16th edition. Association of Official Analytical Chemists, Washington, DC, U.S.A.

Awolu, O.O., Omoba, O.S., Olawoye, O. and Alakowe, A.T. (2017). Development of novel cookies enriched with okara and roasted tigernut flour. *Food Science and Nutrition.* **4(6):** 1-9.

Bachate, A.H., Pawar, V.S., Pawar, G.S., Rodge, S. M. and Joshi, M.M. (2025). Effect of soaking, roasting and germination on nutritional quality and colour properties of pearl millet flour. *Asian Journal of Dairy and Food Reaserch*. 1-60. doi: 10.18805/ajdfr. DR-2371.

Bello, M.O., Fashakin, J.B. and Abioye, V.F. (2017). Effect of roasting on the physicochemical and sensory properties of some legume flours. *International Food Research Journal.* **24(2):** 620-626.

Beniwal, S.K., Devi, A. and Sindhu, R. (2019) Effect of grain processing on nutritional and physico chemical, functional and pasting properties of amaranth and quinoa flours. *Indian Journal of Traditional Knowledge*. **18(3):** 500-507.

Bhat, S. Nandini, C. Tippeswamy, V. Prabhakar. (2018). Significance of small millets in nutrition and health- A review. *Asian Journal of Dairy and Food Research*. **37(1):** 35-40. doi: 10. 18805/ajdfr.DR-1306.

Chavan, J.K., Kadam, S.S. and Salunkhe, D.K. (2013). Nutritional Improvement of Cereals by Processing. CRC Press.

Fasasi, O.S. (2009). Proximate, antinutritional factors and functional properties of processed pearl millet (*Pennisetum glaucum*). *Journal of Food Technology*. **7:** 92-97.

Gamel, T.H., Linssen, J.P., Mesallam, A.S., Damir, A.A. and Shekib, L.A. (2006). Effect of seed treatments on physicochemical properties of amaranth flour. *Journal of the Science of Food and Agriculture*. **86(3):** 353-359.

Gamel, T.H., Mesallam, A.S., Damir, A.A. and Linssen, J.P. (2016). Changes in protein solubility, digestibility and amino acid profile during germination of amaranth grain. *LWT–Food Science and Technology.* **65:** 451-457.

Gao, Q., Wang, Y. and Zhao, J. (2014). Structural characterization and adsorption properties of porous starch. *International Journal of Food Science and Technology.* **49(9):** 2039-2047. https://doi.org/10.1111/ijfs.12512.

Jan, N., Hussain, S.Z.., Naseer, B. and Bhat, T.A. (2023). Amaranth and quinoa as potential nutraceuticals: A review of anti-nutritional factors, health benefits and their applications in food, medicinal and cosmetic sectors. *Food Chemistry.* X 18.112.

Joshi, A.A., Kshirsagar, R.B., Sadawarte, S.K., Patil, B.M. and Sawate, A.R. (2022) Comparative evaluation of baking and functional qualities of black wheat flour. *The Pharma Innovation Journal*. **11(3):** 229-234.

Karamac, M.F., Gai, E., Longato, G., Meineri, M.A., Janiak, R., Amarowicz. and Peiretti, P.G. (2019). Antioxidant activity and phenolic composition of amaranth (*Amaranthus caudatus*) during plant growth. *Antioxidants*. **8(6):** 173-178.

Khan, M., Singh, S. and Sharma, P. (2013). Effect of germination on nutritional composition of seeds. *Journal of Food Science and Technology.* **50(6):** 1091-1096.

Komi, K.F., Nkama, I. and Jideani, V.A. (2008). Quality characteristics of roasted cereal grains: Effects of processing on moisture, texture and nutritional value. *Journal of Food Technology.* **6(4):** 175-181.

Larsson, M. and Sandberg, A.S. (1992). Phytate reduction in oats during malting. *Journal of Food Science*. **57(4):** 994-997.

Maldonado-Cervantes, E., Hernández-Uresti, D.B., Ramírez-Jiménez, A.K. and Castro-Rosas, J. (2019). Impact of germination on nutritional and functional properties of cereal grains. *Food Reviews International.* **36(2):** 1-17.

Mane, R.P., Kshirsagar, R.B., Agarkar, B.S., Patil, B.M. and Katke, S.D. (2023). Effects of germination on antinutritional, colour, functional and physicochemical properties of millets. *The Pharma Innovation Journal.* **12(1):** 350-355.

Martynez-Villaluenga, C., Penas, B. and Hernandez- Ledesma, (2020). Pseudocereal grains: Nutritional value, health benefits and current applications for the development of gluten-free foods. *Food and Chemical Toxicology*. **137:** 111178. doi:10.1016/j.fct.2020.111178.

Mbithi-Mwikya, S., Camp, J.V., Yiru, Y. and Huyghebaert, A. (2018). Nutrient and functional changes in finger millet during roasting. *Food Chemistry.* **66(1):** 75-79.

Murya, N.K. and Pratibha, A. (2018). Amaranthus grain nutritional benefits: A review. *Journal of Pharmacognosy and Phytochemistry.* **7(2):** 2258-2262.

Mustafa, A.F., Seguin, P. and Gelinas, B. (2011). Chemical composition, dietary fibre, tannins and minerals of grain amaranth genotypes. *International Journal of Food Sciences and Nutrition.* **62(7):** 750-754.

Olagunju, A.I. and Ifesan, B.O. (2021). Effect of soaking and boiling on functional properties of millet flour. *Journal of Food Quality*. 1-8.

Onwuka, G.I. (2005). Food Analysis and Instrumentation: *Theory* and *Practice.* Napthali Prints.

Panse, V.S. and Sukhatme, P.V. (1985). Statistical Methods for Agricultural Workers (4th ed.). New Delhi: Indian Council of Agricultural Research (ICAR).

Rao, B.D., Devaraj, V.R. and Reddy, T.P. (2013). Biochemical changes in phenols, flavonoids, tannins, vitamin E, β-carotene and antioxidant activity during soaking of three white sorghum varieties. *Food Chemistry.* **140(1–2):** 109-115.

Sade, F.O. (2009). Proximate, antinutritional factors and functional properties of processed pearl millet. *Journal of Food Technology.* **7(3):** 92-97.

Shinde, E.M. (2023). Studies on development and quality evaluation of low-calorie pasta products form amaranth and barnyard millet. PhD thesis. Vasantrao naik Marathwada Krishi Vidyapeeth Parbhani, Maharashtra, India.

Singh, A. and Punia, D. (2020). Characterization and nutritive values of amaranth seeds. *Current Journal of Applied Science and Technology.* **39(3):** 27-33.

Singh, A. and Singh, S. (2020). Effect of thermal processing on grain protein functionality. *Journal of Food Processing and Preservation.* **44(7):** e14523.

Singh, A., Gupta, S., Kaur, R. Gupta and H.R. (2017). Process optimization for anti-nutrient minimization of millets. *Asian Journal of Dairy and Food Research*. **36(4):** 322-326. doi: 10. 18805/ajdfr.DR-1215.

Sogut, E. and Seydim, A.C. (2018). The effect of germination on bioactive compounds and physicochemical properties of grains and legumes: A review. *Food Reviews International.* **34(6):** 708-725.

Teresa, A. and Pag, M.J. (2021). Green or clean? Perception of clean label plant-based products by omnivorous, vegan, vegetarian and flexitarian consumers. *Food Research International.* **149(8):** 110652. doi: 10.1016/j.foodres.2021.110652.

Thakur, P., Kumara, K., Ahmeda, N., Chauhana, D., Hyder Rizvia, Q.U.E., Jana, S., Singha, T. P. and Dhaliwal, H.S. (2021). Effect of soaking and germination treatments on nutritional, anti-nutritional and bioactive properties of amaranth (*Amaranthus hypochondriacus* L.), quinoa (*Chenopodium quinoa* L.) and buckwheat (*Fagopyrum esculentum* L.). *Current Research in Food Science*. **4:** 917-925.