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Comparative effects of pretreatments and their combinations on uncooked and microwave-assisted cooked lentil (*Lens culinaris*) technofunctional, antinutritional, bioactive, and structural properties

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Abstract

This study focused on the nutritional, technofunctional, bioactive, and microstructural properties of lentils obtained with different pretreatments and processing methods, including soaking, germination, dehulling, microwave-assisted cooking (MAC), and their combinations, to produce value-added lentil flour with improved characteristics. The combination of dehulling and germination resulted in a significant increase in protein content ($p < 0.05$), with the highest value of 30.91%. Similarly, crude fiber content increased due to the combined effects of germination and MAC (3.62%). In contrast, fat content showed a decreasing trend. Dehulling resulted in maximum reduction of tannin content (85.57%), phytic acid was most effectively reduced by germination (73.14%), and trypsin inhibitor was majorly reduced by MAC (93.81%). Antioxidant activity was highest in the untreated sample (35.37%) and decreased further after subsequent pretreatments; a similar reduction was observed for TPC. Soaking dehulled lentil flour resulted in the highest peak and final viscosities (1366 cP; 1800 cP). MAC can improve both the technofunctional and nutritional properties of lentil flour, and a combination approach can enhance lentil value and diversify its use.

Keywords: *Lentil flour; Germination; Microwave-assisted cooking; Antinutrients; Technofunctional properties; Bioactive; Pasting*

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1. Introduction

Lentils (*Lens culinaris*) are increasingly recognized internationally as a sustainable source of protein owing to their minimal environmental impact, relatively modest water needs, and capacity to enhance soil health.[1] They rank among the most economical vegetarian protein sources, and their escalating application in plant-based and functional food products reflects a rising demand for sustainable, transparent, and nutrient-dense ingredients. However, integrating lentils into plant-based foods often poses challenges, including longer cooking times, which can diminish their nutritional value and require greater energy consumption. Moreover, lentils contain significant levels of antinutrients, which reduce their bioavailability and thereby limit their utilization.[2] Effectively reducing these antinutritional components while maintaining nutritional quality remains a vital obstacle in lentil processing.

To address these challenges, various traditional and thermal treatments used in industry, such as soaking, germination, dehulling, and cooking, may be utilized. Soaking is a simple, industry-aligned first step that hydrates lentils, leaches water-soluble antinutrients into soaked water, and reduces cooking time. Studies on red and green lentils reported reductions in phytic acid and trypsin of 14.5–43.8% and 58.2–80.1%, respectively, following soaking and drying.[3] Germination effectively reduces antinutrients (phytates, tannins, etc.) by activating endogenous phytases and proteases, while improving vitamin and antioxidant profiles and often enhancing technofunctional properties (hydration, emulsification).[4] Dehulling removes the seed coat, thereby decreasing phytic acid, condensed tannins, and polyphenols, thus increasing bioavailability despite a reduction in polyphenols or minerals.[5]

Dehulling, soaking, and germination are widely used household- and industry-scale processing methods. After pretreatments, cooking is done either traditionally using thermal methods (most commonly used in households and industries) or using alternative thermal technologies. Traditional cooking significantly reduces antinutritional factors in legumes and plant-based

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foods.[6] However, this method might be energy-intensive, require a longer duration, lead to higher leaching losses, degrade heat-sensitive qualities, and decrease levels or bioavailability of some bioactive compounds.[7] These limitations have prompted the exploration of alternative thermal technologies, notably microwave technology.

Microwave processing has opened a range of opportunities for the food industry, offering time and energy savings and less degradation in the nutritional quality of foods without compromising safety.[8] Microwave heating relies on the specific characteristics of the material, including electrical conductivity, moisture content, and dielectric properties, to directly heat the product by generating heat within it.[7,8] The heating effect, therefore, arises from friction between molecules, which occurs through ionic conduction and dipolar rotation, thereby absorbing electrical energy from the electromagnetic field.[9] In contrast to conventional boiling, which leads to significant nutrient loss, microwave cooking expedites cooking and preserves the optimal nutritional content of lentils.[10] A comparison of microwave, pressure, and conventional cooking of lentil and other legume pastes found that microwave cooking yielded the highest soluble solids, improved protein digestibility, and beneficial changes in protein and bioactive release, highlighting the potential of microwave processing to enhance nutrient accessibility in legumes.[11] In a separate investigation of rice, microwave heating produced results comparable to traditional cooking with shorter time and less water usage.[12] Contemporary research indicates that microwave-assisted cooking (MAC) facilitates rapid volumetric heating, thereby supporting various applications including blanching, drying, sterilization, and the functional modification of food matrices. This method effectively preserves color, flavor, and vitamins compared with cooking/boiling.[7,8,13-15] Moreover, microwave-induced structural modifications in proteins, starches, and lipids can enhance the technofunctional properties of processed foods. These benefits position MAC as a thermally

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based method that aligns with sustainability considerations and offers nutritional advantages compared to traditional cooking techniques.

Existing research has investigated pretreatment strategies, including dehulling, germination, and thermal processing, to improve the palatability and nutrient bioavailability of pulses, as well as their effects on compositional and functional attributes.[4,6] Although soaking, germination, dehulling, and cooking have each been shown to reduce antinutritional factors and improve the nutritional quality of lentils and related legumes, most studies evaluate these treatments independently or under conventional heating conditions. Consequently, comparative and systematic assessments of combined pretreatments, particularly regarding their technofunctional behavior, antinutrient reduction, and microstructural transformations, remain limited, and research integrating these pretreatments with MAC is notably scarce. Given their feasibility and scalability within pulse-ingredient processing, these pretreatments were selected to address this gap. Therefore, the present study investigates the effect of dehulling, soaking, and germination, applied individually and in combination using a general full factorial design, on the technofunctional, bioactive, antinutritional, and microstructural properties of lentil flours under both raw and microwave-cooked conditions.

2. Materials and Methods

2.1. Materials

Red lentils (*Lens culinaris*) of the PL8 variety, cultivated in Punjab (India), were obtained from Longowal village market within 2 months of harvest, with a thousand-kernel weight of 41.5±3.45 g. After being cleansed and freed from dust and other foreign matter, the seeds were stored in zip-lock bags, sealed, and kept at room temperature until further use. All the reagents and chemicals used were of analytical reagent grade.

2.2. Preparation of lentil flour

The lentil seeds were pretreated with dehulling, soaking, and germination, individually and their combinations (soaking + dehulling, germination + dehulling), followed by drying and milling for all samples. Initially, a batch of seeds (200 g) was cleaned and rinsed, then soaked at ambient temperature (22-25 °C) for 12 h with a seed mass-to-water volume ratio of 1:4 (w/v). After soaking, the water was drained, and half of the seeds were retained as soaked samples. In contrast, the remaining half was germinated for 40 h at 27 °C in an environmental chamber (MSW-125, Micro Scientific Works Pvt. Ltd., New Delhi, India), resulting in germinated samples. Germination was carried out at 92% relative humidity under dark conditions. The soaked seeds were wrapped in a clean cotton cloth, placed on a stainless-steel tray, and transferred into the environmental chamber for germination. After soaking and germination, half of the seeds were manually dehulled with hands to avoid cotyledon damage, and the other half were left with their hulls, yielding whole and dehulled samples. All six samples after the desired pretreatments were dried in a hot-air oven (IG-50HAO, iGene Labserve Pvt. Ltd., New Delhi, India) at 45±2 °C until a final moisture content of 10% was achieved. Moisture content was monitored using the AOAC oven-drying method (AOAC 925.10); drying time (12-14 h) was varied until the final moisture content was reached.[16] The drying process was followed by milling (Supermix, Sujata Appliances, Mittal Electronics, New Delhi, India), sieving through a 150 µm sieve to obtain a standardized sieve-classified fraction with an upper particle size limit of 150 µm, and storing the powder in airtight pouches. The particle size distribution analysis was not performed, and thus, the actual particle size of the flour is not known, which is a limitation of this study. The samples were designated as WLF (whole lentil flour), DLF (dehulled lentil flour), SWLF (soaked whole lentil flour), SDLF (soaked dehulled lentil flour), GWLF (germinated whole lentil flour), and GDLF (germinated dehulled lentil flour) (Fig. 1A).

Another set of six samples was prepared in the same way, with an additional MAC step. A detailed step-by-step process is shown in Fig. 1B. Fifty grams of each sample (seeds) were

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transferred into a 500 mL microwave-safe glass beaker, with an internal diameter of 87 mm and a height of 127 mm, and supplemented with distilled water (at room temperature) at a seed mass-to-water volume ratio of 1:4 (w/v). The cooking process was performed at 800 W in the microwave oven (MS23K3513AK/T, Samsung, Malaysia), with the beaker kept open and not stirred until cooking was complete. The cooking endpoint was identified by the same trained operator throughout the study, using a standardized method.[17] Accurately, 10 grains were tested every minute by pressing them between the fingers, and the endpoint was defined as the point at which no hard core remained after 30 s of cooling. The cooking time was 13 minutes. However, this method relies on sensory endpoint assessment and was not validated using instrumental methods (e.g., texture analysis), which is a limitation. After treatment, the cooking liquor was discarded, and the respective samples were cooled, dried, ground, sieved, and stored for further analysis.

2.3. Proximate composition

The moisture content of the lentil flour samples was determined by oven drying in accordance with AOAC 925.10. Nitrogen content was analyzed utilizing the Kjeldahl method (AOAC 920.87), and protein content was computed by multiplying the nitrogen value by a conversion factor of 6.25. Ash content was also measured using a Muffle furnace according to the procedures outlined by AOAC (AOAC 923.03).[16] Crude fat content was estimated by Soxhlet extraction, as specified in the AOAC guidelines.[18] Finally, the carbohydrate (CHO, %) content was calculated as the difference: (Carbohydrate% = [100 − moisture% – protein% – fat% – ash% – crude fiber%]).[19]

2.4. Technofunctional properties

2.4.1. Water and oil absorption capacity (WAC/OAC)

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WAC and OAC were measured using the method described by Mandliya et al. with slight modifications.[20] One gram of lentil flour was placed in a pre-weighed centrifuge tube, followed by the addition of 10 mL of distilled water. The samples were vortexed for one min at 3000 rpm, allowed to stand for 30 min, and then centrifuged at 4000 rpm (~1794 ×g) for 25 min in a refrigerated centrifuge (CIC 671, RC 4100F, Elektrocraft India Pvt. Ltd, Mumbai). The supernatant was removed, and the wet sample in the tube was weighed. Similarly, for OAC, distilled water was replaced with refined rice bran oil (density 0.92 g/mL), with the same procedure. The weights of water- and oil-bound samples were determined, and WAC and OAC were calculated as described in Eq. (1), with results expressed as g water/g sample for WAC, and g oil/g sample for OAC, reported on a wet basis.

$$\mathrm{WAC/OAC} = \frac{\mathrm{W}_3 - \mathrm{W}_1}{\mathrm{W}_2} \tag{1}$$

Where W_1 is the weight of the empty centrifuge tube (g), W_2 is the initial weight of the sample (g), and W_3 is the weight of the tube with the precipitate (g).

2.4.2. Emulsifying capacity

The assessment of flour's emulsifying capacity (EC) followed the methodology outlined by Badia-Olmos et al. with a few changes.[21] One gram of flour was mixed with 40 mL of an oil-water mixture (1:1 v/v water:oil), prepared by blending distilled water with refined rice bran oil. The resulting mixture was homogenized using a homogenizer (Model MT-30K, Moxcare, India) at 10,000 rpm for one min; subsequently centrifugation was carried out at 6000 rpm (4025 ×g) for 30 min using a refrigerated centrifuge. All the measurements were taken immediately after centrifugation. The volume of the emulsified layer was measured to facilitate the calculation of EC (%), defined as the height of the emulsified layer divided by the total height (Eq. 2).

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$$\text{EC}\ (\%) = \frac{\text{Height of emulsified layer in the tube}}{\text{Total height in the tube}} \times 100 \qquad (2)$$

2.4.3. Foaming capacity

The methodology for assessing the foaming capacity (FC) of lentil flours was based on the procedures outlined by Badia-Olmos et al.[21] One gram of flour was dispersed in 50 mL of distilled water and homogenized using a homogenizer (Model MT-30K, Moxcare, India) at 13500 rpm for two min at ambient temperature (25 ± 2 °C). The height of the resulting foam was measured immediately by pouring the sample into a graduated cylinder and visually estimating its volume. FC was expressed as the percentage increase in volume due to foam formation, as defined in Eq. (3).

$$\text{FC}\ (\%) = \frac{\text{Volume after whipping} - \text{Volume before whipping}}{\text{Volume before whipping}} \times 100 \qquad (3)$$

2.5. Antinutrients and bioactives

2.5.1. Phytic acid

The test for phytic acid was performed according to the methodology of Gupta et al. with slight modifications.[22] Briefly, 0.2 g of lentil flour was weighed, and 2% (v/v) HCl was added, and the mixture was allowed to react for 3 h. The digested samples were then filtered. 50 mL of the filtered extract from each sample was mixed with 10 mL of distilled water, then with 10 mL of 0.3% ammonium thiocyanate. The resultant solution was titrated with a ferric chloride solution (0.00195 g iron/mL) until a permanent yellow color persisted; after a 5-minute interval, this yellow color indicated the endpoint. The phytic acid content was determined using Eq. (4).

$$\text{Phytic acid content} = \frac{\text{Titer value} \times 0.00195 \times 1.19}{\text{weight of sample}} \times 100 \qquad (4)$$

2.5.2. Tannin content

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The vanillin hydrochloride method was used to determine the tannin content in the lentil samples. The test was initiated by adding 0.2 g of lentil flour to 10 mL of methanol, followed by centrifugation for 15 min at 6000 rpm (4025 ×g). Afterwards, 1 mL of supernatant was mixed with 5 mL of vanillin hydrochloride reagent and incubated at 30 °C for 20 min, as outlined by Palacios et al. with minor modifications.[23] The absorbance was then measured at 500 nm using a spectrophotometer (HACH, DR-6000, Dusseldorf, Germany). The tannin content was expressed as mg of catechin equivalents per g of lentil flour based on a dry weight basis (mg CE/g dw).

2.5.3. Trypsin inhibitor activity

The assessment of Trypsin inhibitor followed the methodology outlined by Martinez-Gonzalez et al. with slight changes.[24] The test was initiated by dissolving 0.5 g of the sample in 25 mL of 0.01 N NaOH, followed by centrifugation at 6000 rpm (4025 ×g) for 15 min. Subsequently, 2 mL of the supernatant was added to 2 mL of trypsin solution, and the mixture was incubated for 10 min at 37 °C. The *N*-α-benzoyl-DL-arginine-4-nitroanilide (BAPNA) solution, prepared in 0.05 M tris buffer containing 0.02 M calcium chloride (5 mL) was added, and the reaction was stopped after 10 min with the addition of 1 mL of 30% acetic acid solution. The mixture was filtered, and its absorbance was measured at 410 nm using a spectrophotometer. The trypsin solution was added to acetic acid, and the number of trypsin-inhibited units (TIU/mg dw) was used to quantify trypsin inhibitory activity. One TIU was defined as the amount of inhibitor that causes a decrease of 0.01 absorbance units at 410 nm under the specified assay conditions.

2.5.4. Total phenolic content (TPC) and Antioxidant activity (AOX)

TPC in lentil flour samples was measured using the Folin-Ciocalteu method as described by Vishwakarma et al., with minor modifications.[25] A 10 mg/mL methanolic extract was

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prepared for analysis. Subsequently, 0.5 mL of the methanolic extract was mixed with 2.5 mL of 10% Folin-Ciocalteu reagent and 2.5 mL of 7.5% Na_2CO_3. Similarly, a blank was prepared with all reagents at the same amounts, except for the sample, which received 0.5 mL of methanol instead. All prepared samples were incubated in the dark for 60 min at 25 °C, and a mild blue color developed. Absorbance was measured at 765 nm using a spectrophotometer. Gallic acid standard solutions were used to develop a calibration curve ($R^2 > 0.98$), and the calculated TPC values were expressed as mg gallic acid equivalents per g of sample on a dry weight basis (mg GAE/g dw).

The antioxidant activity (AOX) of lentil samples was measured using the DPPH assay, as described by Pathiraja et al., with minor modifications.[26] Briefly, 24 mg of DPPH were dissolved in 100 mL of methanol to create a methanol stock solution, which was then diluted with methanol. An aliquot of 100 μL of each sample was mixed with 3 mL of DPPH stock solution, shaken well, and incubated in the dark for 30 min. A blank was then prepared without extract and measured at 517 nm. The % DPPH inhibition was calculated using Eq. (5).

$$\%\ \text{DPPH Inhibition} = \frac{\text{Ac} - \text{As}}{\text{Ac}} \times 100 \quad (5)$$

Where Ac and As are the absorbance of the control and the absorbance of the sample, respectively.

2.6. Pasting properties

The pasting profile was determined with Rapid Visco Analyzer (RVA) (TecMaster, Warriewood, Australia) as described by Vishwakarma et al.[25] A designated heating and cooling cycle was programmed, involving a 3 g sample with distilled water added to attain the appropriate moisture content for viscosity profile generation. The experimental procedure involved initially holding the samples at 50 °C for 1 min, then heating to 95 °C at 12 °C/min, and holding at 95 °C for 2.5 min. Subsequently, the samples were cooled from 95 °C to 45 °C

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at 12 °C/min, followed by a 2-min holding period at 45 °C. All the samples were subject to the same procedure.

2.7. Morphological analysis

The morphological characteristics of lentil flour samples were analyzed using scanning electron microscopy (SEM) (JSM-7610F Plus, JEOL, Japan) with secondary electron (SE) detector to examine the microstructural changes under high vacuum conditions induced by different pretreatments in both raw and MAC samples. Each sample was sputter-coated with a thin layer of gold (360 Å thickness) under vacuum at room temperature before image analysis.[27] A 10 kV power was used at 850× and 1000× magnifications.

2.8. Statistical analysis

The experiment employed a full factorial design to assess the effects of cooking methods (2: raw and microwave-assisted) and pretreatments (5: soaking, germination, dehulling, soaking + dehulling, and germination + dehulling) on proximate, technofunctional, antinutrient, and bioactive properties. Two control samples were included – one for raw and another for MAC without any pretreatment. All experimental runs were conducted in triplicate, with the analyzed properties expressed as mean ± standard deviation across biological replicates. An analysis of variance (ANOVA) was performed to determine the statistical significance of the effects of cooking, pretreatment, or their interaction on the measured responses. The mean comparisons were performed using Tukey's HSD test to delineate differences among factor levels at the 0.05 significance level (α). All statistical analyses were conducted using OriginPro 2021 (OriginLab Corporation, Northampton, MA, USA).

3. Results and Discussion

3.1. Proximate composition

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The proximate composition of the lentil flour samples, as presented in Table 1, reflects their nutritional attributes. The absolute protein content in raw and MAC-treated samples ranged from 26.68% to 30.91% and from 25.88% to 27.98%, respectively, demonstrating a statistically significant difference ($p<0.05$). The protein content of lentil increased by both soaking and germination, which may be associated with enzyme synthesis, amino acid release, and breakdown of protein molecules into simpler peptides. Furthermore, the breakdown and utilization of carbohydrates and lipids as energy sources during germination may result in a relative increase in protein concentration when expressed on a dry-weight basis, a significant decrease in absolute protein content was observed after MAC, which may be attributed to the leaching out of nitrogenous compounds and soluble proteins into the cooking water.[28] Additionally, prolonged heat exposure can lead to protein denaturation and aggregation, which may reduce protein content.[29] Although protein losses in the cooking water or changes in protein solubility were not directly quantified in the present study, these mechanisms are widely reported and are likely contributors to the observed reduction. It was observed that dehulling, germination, and their combined treatment had the most significant impact on raw lentil flour samples, resulting in absolute protein percentages of 28.97%, 29.02%, and 30.91%, respectively.

Fat content was significantly influenced by cooking treatment (MAC) and pretreatment. MAC samples exhibited lower fat levels (0.74–1.03%) than their raw counterparts (1.29–1.52%), indicating a stronger effect of MAC. Among raw samples, dehulled flours (DLF, SDLF, and GDLF) had higher fat content compared to whole lentil flours (Table 1). The observed rise in fat content subsequent to dehulling in raw flours presumably indicates a compositional redistribution following hull removal, given that lipids are predominantly accumulated within the cotyledon fraction. Germination showed a tendency toward reduced fat levels, which may indicate lipid utilization during metabolic processes; however, these differences were relatively

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minor compared with those observed with MAC. MAC decreased fat content by a larger margin, which may be associated with the diffusion of lipid into water during cooking.

The crude fiber content in raw and MAC samples ranged from 1.05% to 3.84% and 1.51% to 4.32%, respectively. The seed coat contains the majority of this fiber; dehulling lentils reduces fiber content in both raw and MAC samples, thereby increasing protein content.[30] Both the raw and MAC lentil samples exhibited a significant ($p<0.05$) increase in crude fiber following germination compared to their non-dehulled counterparts. Since crude fiber primarily comprises cellulose, lignin, and hemicelluloses, the observed increase in its content may be associated with the accumulation of dry matter as the seed undergoes germination.[31] MAC samples had higher crude fiber levels than their raw counterparts. This phenomenon may be attributed to the formation of protein-fiber complexes that develop during MAC.[32] The GWLF of MAC yielded the highest crude fiber content, which may be ascribed to the combined effects of fiber accumulation during germination and structural modifications induced by MAC. Furthermore, the presence of the seed coat, which was not removed in these samples, likely contributed to the increased crude fiber content.

Both raw and MAC-treated lentil samples showed a non-significant ($p>0.05$) decrease in ash content. Among the treated samples, a slight reduction in ash content was observed for SWLF following MAC. This slight decrease may be attributed to the leaching of mineral components into the cooking medium during processing, a trend consistently reported in earlier studies on thermally processed legumes.[4]

There is a notable absolute decrease in the total carbohydrate content in raw samples following pretreatments, as shown in Table 1. The most significant reduction ($p<0.05$) was observed in the germinated samples (GWLF and GDLF) for both raw and MAC. During germination, seeds activate enzymes that break down complex carbohydrates (starch) into simpler sugars and, during respiration, glucose is metabolized into carbon dioxide and water, leading to a loss of

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carbohydrate mass from the seed and an overall reduction in total carbohydrate.[33] A similar downward trend was observed in MAC-treated samples. Nevertheless, an overall relative increase in total carbohydrate content was observed following MAC. This apparent increase does not indicate a gain or enrichment attributable to cooking; rather, it reflects reductions in other components (protein, fat, and ash) and leaching during MAC.

3.2. Technofunctional properties

3.2.1. Water and oil absorption capacity

Technofunctional properties, such as WAC and OAC, directly affect the performance, texture, mouthfeel, and stability of food products, offering valuable insights into flour behavior during processing.[34] WAC and OAC of the lentil flours showed a significant ($p<0.05$) increase for the germinated samples, both for GWLF and GDLF (Raw and MAC), as shown in Table 2. In raw flours, GDLF (1.26 g/g) exhibited higher WAC, indicating that germination and dehulling improved hydration capacity. This improvement is potentially attributable to modifications in protein–polysaccharide structures and increased porosity, as evidenced by SEM analysis (Fig. 3(i)). Furthermore, germination increased both WAC and OAC of raw lentil flour, ranging from 23.52% to 27.27% and from 62.59% to 94.62%, respectively, compared with their non-germinated counterparts (WLF and DLF). Similarly, a significant ($p<0.05$) increase was observed following dehulling (DLF, SDLF, and GDLF).

A consistent pattern was observed in the MAC flour samples after germination, with WAC increasing by 35.96-60.44% and OAC by 50.77-75.16% compared to their non-germinated MAC counterparts. Lentils, when soaked, absorb water, leading to softening of the seed coat and cotyledon, which in turn increases their WAC.[35] Microwave treatment may trap more water molecules by unfolding proteins. Moreover, microwave energy penetrates deeply, generating rapid internal heating that causes the food matrix to expand. This volumetric

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expansion may result in the formation of micro-pores and cracks within the structure, increasing the surface area and the availability of binding sites for water and oil molecules.[36] This is also evident in the later sections describing morphological changes (Fig. 3 ii). Moreover, it was observed that soaked and germinated samples responded more strongly to MAC. During MAC, proteins may denature upon heating, and exposed hydrophobic sites may increase lipid interactions, resulting in an overall increase in OAC (36.12–116.96%) compared to their raw samples.[37]

3.2.2. Emulsifying capacity

An increase in EC was observed in dehulled samples compared with their non-dehulled counterparts for both raw and MAC treatment (Table 2). This increase is likely related to the exposure of cotyledons, which are rich in proteins. Dehulling consequently increased protein content, which in turn increased the EC (36.31-62.77%) in raw and (24.76-36.40%) in MAC samples. An increase in EC was observed following MAC, which may be attributed to the dissociation and partial unfolding of polypeptides, accompanied by enzymatic modification of storage proteins during germination, resulting in smaller, more flexible, and surface-active protein fractions. These changes may improve protein solubility and availability, thereby promoting rapid adsorption at the oil-water interface and increasing EC in germinated samples (Raw: 22.08-45.73%, and MAC: 19.20-30.32%). Another possible reason for improving the EC in MAC samples may be starch gelatinization, which increases viscosity and provides more hydroxyl groups for hydrogen bonding and physical interactions between proteins and starch.[38,39] Similar improvements in emulsifying behavior have been reported for gelatinized, surface-active starch systems, where increased molecular flexibility enhances interfacial stabilization by modified starches.[40] However, in the present study, gelatinized starch likely supported protein-driven emulsification rather than acting as an independent emulsifier.

3.2.3. Foaming capacity

FC is measured to evaluate the ability of proteins to entrap and stabilize air when whipped or agitated, an important technofunctional property in many aerated food products.[41] FC of the raw lentil flour increased significantly ($p<0.05$) with dehulling and germination as compared to soaking (Table 2). Dehulling removes the hull and thereby increases the protein content in the cotyledon on a dry-weight basis, resulting in higher FC in raw (9.30-16.67%) and MAC (1.74-3.60%) samples compared to their non-dehulled counterparts. A similar pattern was observed in germinated samples, with raw samples showing 23.10-29.81% and MAC samples showing 14.52-16.27% increase compared to their control counterparts. As previously discussed, during germination, proteolytic enzymes partially hydrolyze storage proteins into smaller, more flexible peptides, which may swiftly migrate to the air-water interface, decrease surface tension, and form more stable foams than intact proteins.[42]

Unlike other technofunctional properties, MAC treatments decreased FC, consistent with the findings of Mahalaxmi et al.[43] Although proteins are generally regarded as foam stabilizers, prolonged thermal unfolding and subsequent aggregation during MAC compromise their interfacial film-forming ability, thereby decreasing foamability.[41] It is evident that MAC exerts a significant ($p<0.05$) influence on FC, compared with pretreatments, indicating that MAC diminishes the sensitivity of FC to prior pretreatments. This loss of significance can be attributed to the thermal sensitivity of foaming properties, as extensive protein denaturation and aggregation during MAC likely dominate interfacial behavior, consequently reducing the relative impact of individual pretreatments and resulting in an overall decrease in FC.

3.3. Antinutritional factors

3.3.1. Phytic acid

Phytic acid, also known as myo-inositol hexaphosphate, is commonly found in legumes and is considered an antinutritional factor in humans due to the deficiency of the phytase enzyme necessary for its breakdown.[30] In the human digestive system, phytic acid binds to essential minerals such as iron, zinc, and calcium, thereby restricting their intestinal absorption and potentially leading to mineral deficiencies.[44] Initially, the control (raw WLF) sample exhibited a phytic acid content of 10.8±0.02 mg/g dw, which was significantly ($p<0.05$) reduced by various pretreatment combinations and further diminished after MAC. This reduction after individual pretreatments was 49.07% (dehulling), 25% (soaking), and 73.15% (germination), in raw samples, making germination the most efficient method in reducing phytic acid (Table 3). A similar trend was observed in MAC samples as well. This observation corroborates the findings reported by Pal et al.[45]

Overall, GDLF (germination followed by dehulling) reduced phytic acid by approximately 85%. This may be attributed to the dehulling process, followed by germination, which involves enzymatic breakdown and activation of phytase, thereby resulting in a significant reduction in this antinutrient. MAC alone reduced phytic acid by 61.11%, and when combined with pretreatments, it may further reduce it to 94.44% relative to the control raw sample (WLF). This may arise from the heat-sensitive nature of phytic acid; moreover, as a water-soluble component, it facilitates the latching process during cooking.[46] Therefore, in addition to germination, its combination with MAC may be advantageous for substantial reduction.

3.3.2 Tannin content

Tannins, commonly present in legumes, inhibit the activity of enzymes such as trypsin, chymotrypsin, amylase, and lipase, thereby reducing the digestibility of dietary proteins, carbohydrates, and lipids.[47] According to Mirali et al., lentil seed coats contain precursor compounds of tannins, which undergo oxidation over time.[48] This process may results in a deep brown coloration, explaining the significant reduction in tannin levels in dehulled samples compared to whole flours (Raw and MAC). Dehulling decreases tannin content by 81.22-85.57%, soaking by 34.12-41.30%, and germination by 60.42-65.87% in raw samples. Similar

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trends were observed for MAC samples. The majority of tannins are located in the seed coat and are consequently removed during dehulling. Soaking also reduces tannin content, as tannins are water-soluble and tend to leach out during soaking.[49] Germination further reduces tannin levels through enzymatic breakdown and leaching, surpassing the effectiveness of soaking alone.

MAC reduces tannin content by approximately 51.26%. When seeds are heated, especially during cooking, the high temperature may break down tannin-protein and tannin-polysaccharide complexes, releasing tannins, particularly hydrolysable types, which can degrade directly under heat and make them more susceptible to removal.[50] Several studies reported that microwave heating is better than conventional cooking methods for reducing tannins.[51,52] The highest tannin reduction was observed in GDLF, followed by MAC samples, with 97.47% reduction. However, such extensive removal may affect sensory quality and the retention of beneficial polyphenols. Tannins contribute to characteristic flavor attributes, such as astringency, and also possess antioxidant activity. Therefore, while their reduction improves mineral bioavailability and protein digestibility, it may also result in partial loss of health-promoting phenolic compounds, as reflected by decreases in total phenolic content and antioxidant activity (Table 3).

3.3.3 Trypsin inhibitor activity (TIA)

As discussed in the previous sections, trypsin inhibitors can readily interfere with protein digestion, reducing bioavailability. Trypsin inhibitors are protease inhibitor proteins; they are not just simple peptides but are often complex proteins with well-defined tertiary structures that allow them to tightly bind to and inhibit the activity of trypsin and other serine proteases.[53] Dehulling, soaking, and germination resulted in a reduction of trypsin activity by 25.66–36.13%, 56.92-60.25%, and 73.50–75.90%, in raw samples relative to their respective counterparts for individual pretreatment (Table 3). As discussed earlier, germination may activate proteolytic enzymes that facilitate the breakdown of storage proteins and antinutritional factors, including trypsin inhibitors. MAC, on the other hand, was found to be highly effective in significantly reducing TIA by 90.26-93.81%, as trypsin inhibitor is a heat-sensitive compound and therefore inactivated by heat produced by microwaves, resulting in denaturation. GDLF samples subjected to the MAC process showed the lowest TIA (0.06 TIU mg/g dw) among all lentil flour samples; however, higher bioactive reduction was also observed in the GDLF-MAC sample. MAC alone was significantly effective in reducing this antinutrient, indicating its strong independent impact regardless of other pretreatments (Table 3).

3.4. Total phenolic content (TPC) and Antioxidant activity (AOX)

Lentils are known for their rich bioactive compounds (phenolic content and antioxidants), so analyzing the effects of pretreatments, with and without MAC, on these compounds is crucial. TPC and DPPH inhibition activity was highest in the WLF (raw) sample; these values decreased after dehulling, suggesting that the lentil seed coat may also contain TPC and antioxidants (Table 3). Soaking and germination significantly ($p<0.05$) decreased the AOX of raw lentil flours. The percentage reduction in DPPH inhibition activity was around 9.69-20.22% on soaking and 23.24-52.07% after germination. A similar trend was observed for TPC, with a positive correlation.[54] After the MAC, AOX and TPC significantly ($p<0.05$) decreased by 30.71-48.12% and 51.67-66.76%, respectively. As described by Thepthanee et al., considerable levels of phenolic content were detected in soaking, steaming, and boiling water as a result of leaching.[55] Additionally, it has been reported that this reduction results from the mobilization of stored phenolics due to enzyme activation, particularly polyphenol oxidase, during germination.[56] Conversely, Sharma and Sahni reported that lucerne germination improved AOX despite a decline in TPC, indicating that changes in AOX during germination are not solely dependent on phenolic concentration.[57] Dehulling also significantly reduced DPPH inhibition activity and TPC in both raw and MAC lentil flours, as most phenolic compounds in legumes are present in their seed coat.[58] The control sample (WLF-Raw) exhibited the highest TPC and the most potent DPPH radical scavenging activity. MAC treatment resulted in a substantial decrease in TPC and AOX across all pretreatments. GDLF following MAC showed the lowest phenolic level (0.55 mg GAE/g dw), which was significantly lower than that of raw WLF. This consistent downward trend suggests that thermal processing exerts a strong influence on phenolic retention, potentially through mechanisms of degradation or leaching, as evidenced in Table 3.

3.5. Pasting profile

The pasting properties of a food relate to changes that occur when heated up in the presence of water. Such changes influence the digestibility, texture, and, ultimately, the use of the food product. MAC samples exhibited only a negligible increase in viscosity during pasting analysis, unlike raw samples, which showed fully developed curves, as inferred from RVA pasting behavior. This is likely related to prior thermal processing/microwave cooking, which gelatinized the starch and altered its native structure, thereby reducing further viscosity development during this hydrothermal process (Fig. 2). Heating processes such as cooking induce structural modifications in starch, commonly referred to as gelatinization. These modifications result in the release of amylose, the separation of amylopectin double helices, and changes in the starch granule structure. Increased amylose leaching leads to the formation of viscous substances.[59,60] The peak viscosity measures the thickening power of the starch.[61] The SDLF-raw sample has the highest peak viscosity of 1366 cP, followed by the DLF-raw sample, with a peak viscosity of 900 cP (Table 4). In lentils, the combination of soaking, which promotes water penetration, and dehulling, which removes the highly fibrous outer layer, may enhance starch availability and swelling, thereby contributing to the observed higher peak viscosity. Dehulling reduces the non-starch components of lentils, increasing the overall starch

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concentration by weight and thereby improving pasting properties. The study found that α-amylase enzyme, which breaks down starch molecules into simpler units, is responsible for the decrease in peak viscosity.[28] A similar reduction in peak viscosity was observed for GWLF. However, higher peak viscosities indicate greater starch swelling and thickening power, which is favorable in foods such as porridges, soups, and sauces that require rapid starch viscosity development. The control sample (WLF) has the highest breakdown viscosity, indicating the least resilience to heat and shear stress during cooking. This measurement reflects the stability of the starch. According to Awoyale et al., the final viscosity determines the paste's ability to form a viscous paste after preparation, cooking, and cooling, as well as its resistance to shear forces during stirring.[62] The SDLF sample (1800 cP) has the final viscosity, followed by DLF (1216 cP) and SWLF (1214 cP), indicating a stronger paste structure after cooking and cooling with improved gel-forming ability. This suggests a synergistic influence of both soaking and dehulling on starch gelatinization and pasting behavior.

3.6. Morphology

Analyzing flour morphology is essential for understanding the internal physical structure and surface characteristics of flour particles, which directly influence their technofunctional, processing, and nutritional properties. Fig. 3(i) illustrates a uniform microstructure across all raw samples. Smooth-surfaced starch granules were clearly detected, with shapes ranging from ovoid to spherical; they measure 22-30 µm in length and 10-17 µm in width. According to Aguilera et al., the visible, irregular, and dispersed particles above or near the starch granules are either protein bodies or portions of the protein matrix that were broken up during milling; they may also contain fiber components.[63] On the other hand, a slight break in the starch granule surface and a gradual loss of the continuous matrix, which included protein bodies, occurred during soaking (Fig. 3i (C and D)) and germination (Fig. 3i (E and F)). The results agreed with those of Frias et al., who demonstrated physicochemical changes in raw and germinated lentil starch and its components.[64] Dehulling, on the other hand, showed no notable changes in microstructure. Figure 3(ii) presents images captured with SEM of lentil samples that have undergone dehulling, soaking, and germination, and subjected to MAC. The raw and the cooked samples have different microstructures. These granules are larger than those observed in the raw samples, with rugged, irregular surfaces and some broken starch granules. This phenomenon may be attributed to the vaporization of water from the granules, leading to puffing after MAC. The presence of voids and fractured surfaces in MAC samples indicates localized expansion and structural rupture, likely associated with rapid internal heating during MAC. Even a mixture of both proteins and starch could provide a homogeneous network of starch granules cross-linked by proteins. Denaturation of proteins during MAC disrupts the individual protein bodies. The disrupted, porous microstructure of MAC flours is consistent with the higher WAC values, as greater surface roughness and porosity may contribute to increased water entrapment. Similarly, the absence of whole starch granules and the fusion of the matrix are consistent with the reduced pasting values of MAC samples, which showed low viscosity likely influenced by prior starch gelatinization.

3.7. Limitations

This study was conducted on a single lentil cultivar under controlled conditions; therefore, it may not fully reflect the variability observed across cultivars. Additionally, the research was performed at a laboratory scale, necessitating scale-up for commercial applications. The cooking time for MAC was measured manually using a finger-press test performed by a single trained operator, following the standardized method. Although operator consistency was maintained, the absence of instrumental validation (texture analysis) represents a limitation. Furthermore, milling was followed by sieving through a 150 µm sieve. However, no particle size distribution was performed; therefore, homogeneity of particle size within the fraction was not identified. Future investigations should incorporate multiple cultivars, particle size

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distribution, an objective cooking endpoint using texture analysis, and pilot-scale processing to validate and extend these findings.

4. Conclusions

This study demonstrates that pretreatments (dehulling, soaking, germination, soaking + dehulling, and germination + dehulling), either independently or in conjunction with MAC, significantly diminish antinutrients and modulate the technofunctional properties of lentil flour. An increase in protein content was observed following pretreatments; however, this was primarily due to dry matter loss. Conversely, fat content declined slightly across these treatments. The pretreatment methods, particularly when combined with MAC, markedly reduced antinutrients; nonetheless, TPC and AOX were also diminished following these pretreatments. Pretreatments, such as soaking and dehulling, improved the pasting properties of raw lentil flours. The MAC process, combined with pretreatments, improved technofunctional characteristics while preserving important macronutrients; however, a loss of thermosensitive- and hydro-sensitive constituents was evident. These findings support the potential for further research into lentil flours processed as functional food ingredients. Future investigations, including sensory evaluation, mineral bioavailability assessment, and in vivo validation, would deepen the contextual understanding of these results and facilitate the translation of processing methods into valuable and widely acceptable food products.

Conflict of Interest

The authors declare no conflict of interest with respect to the work described in the manuscript.

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CRediT authorship contribution statement

Kathika Das: Conceptualization, Methodology, Formal analysis, Data curation, Investigation, Visualization, Writing – original draft. **Shubham Mandliya:** Formal analysis, Data curation, Investigation, Writing – original draft, Writing – review and editing. **Pradyuman Kumar Baranwal:** Conceptualization, Methodology, Visualization, Resources, Supervision, Writing – review and editing.

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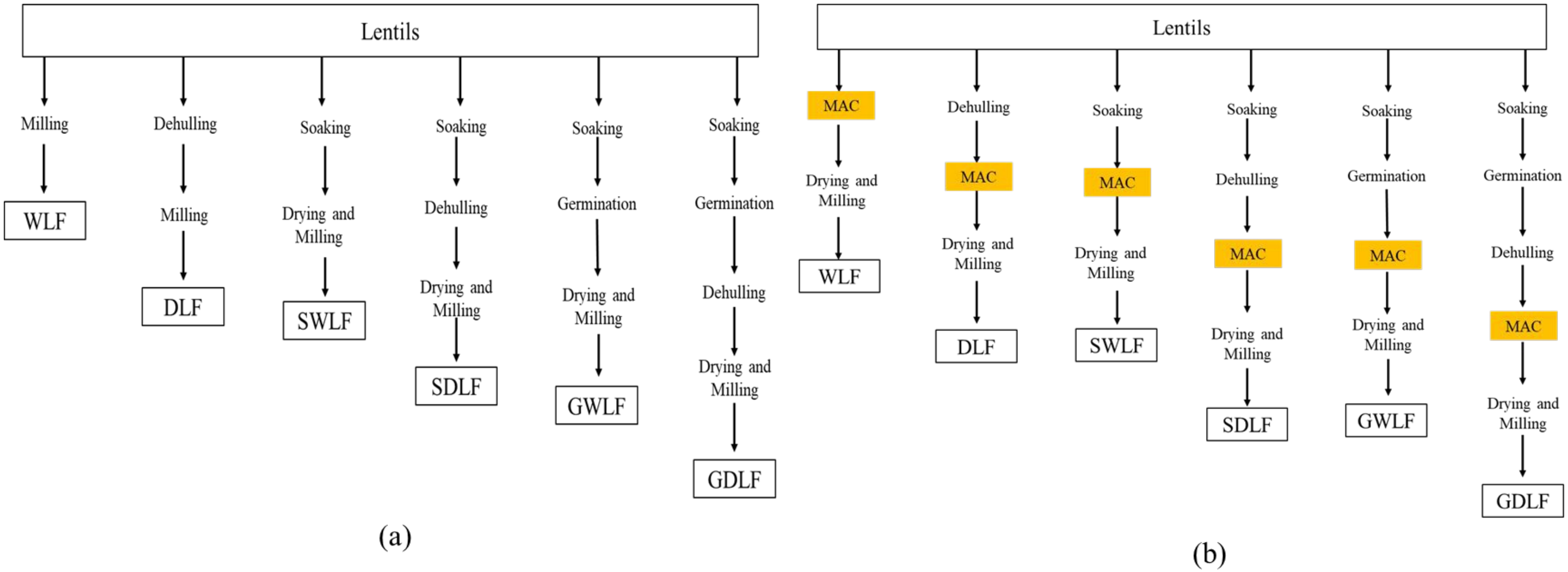


Fig. 1. Processing of (a) raw lentil flour (RAW), and (b) microwave-assisted cooked (MAC) lentil flour with different pretreatments and their combinations. The samples were designated as WLF (Whole lentil flour), DLF (Dehulled lentil flour), SWLF (Soaked whole lentil flour), SDLF (Soaked & dehulled lentil flour), GWLF (Germinated whole lentil flour), GDLF (Germinated & dehulled lentil flour).

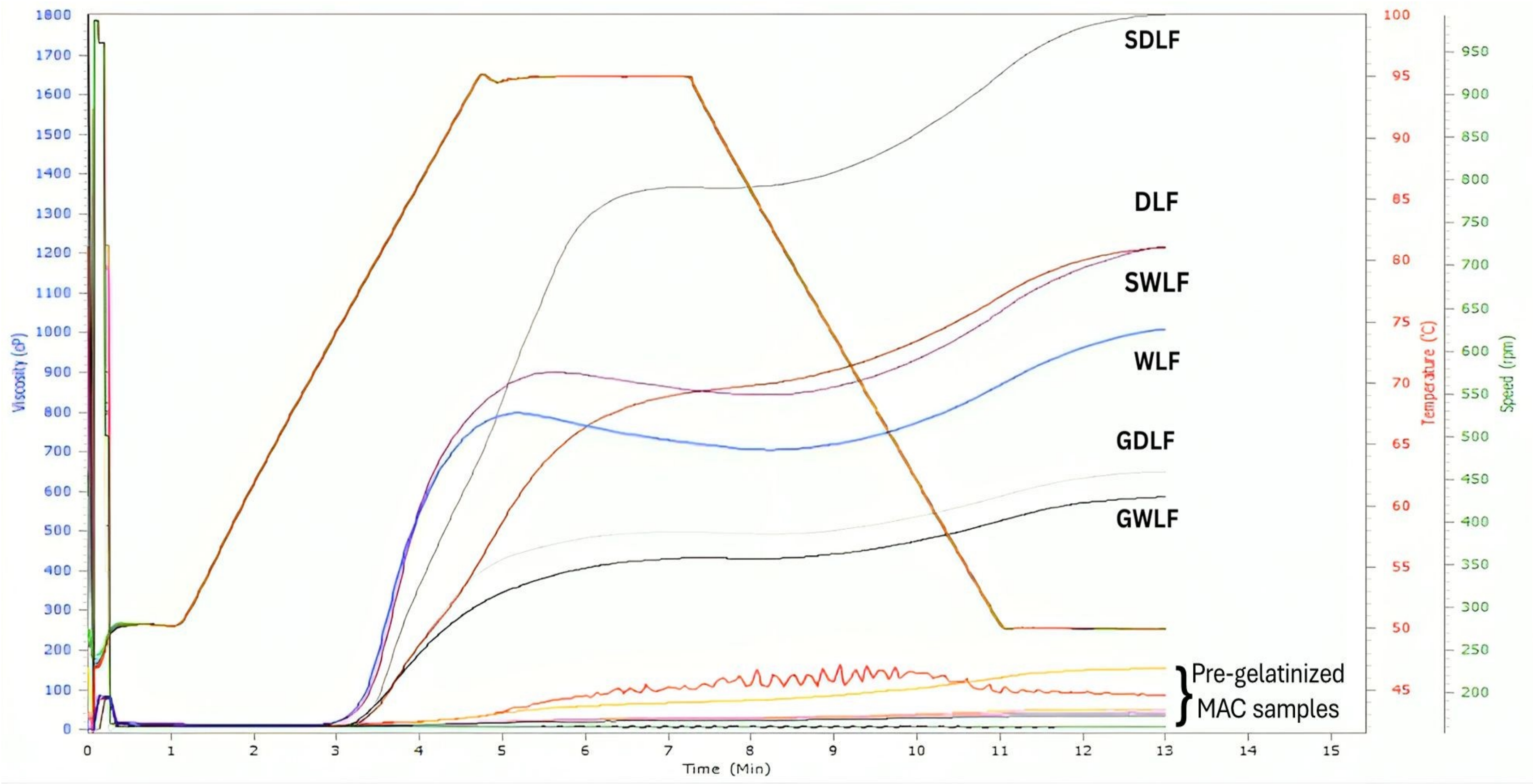
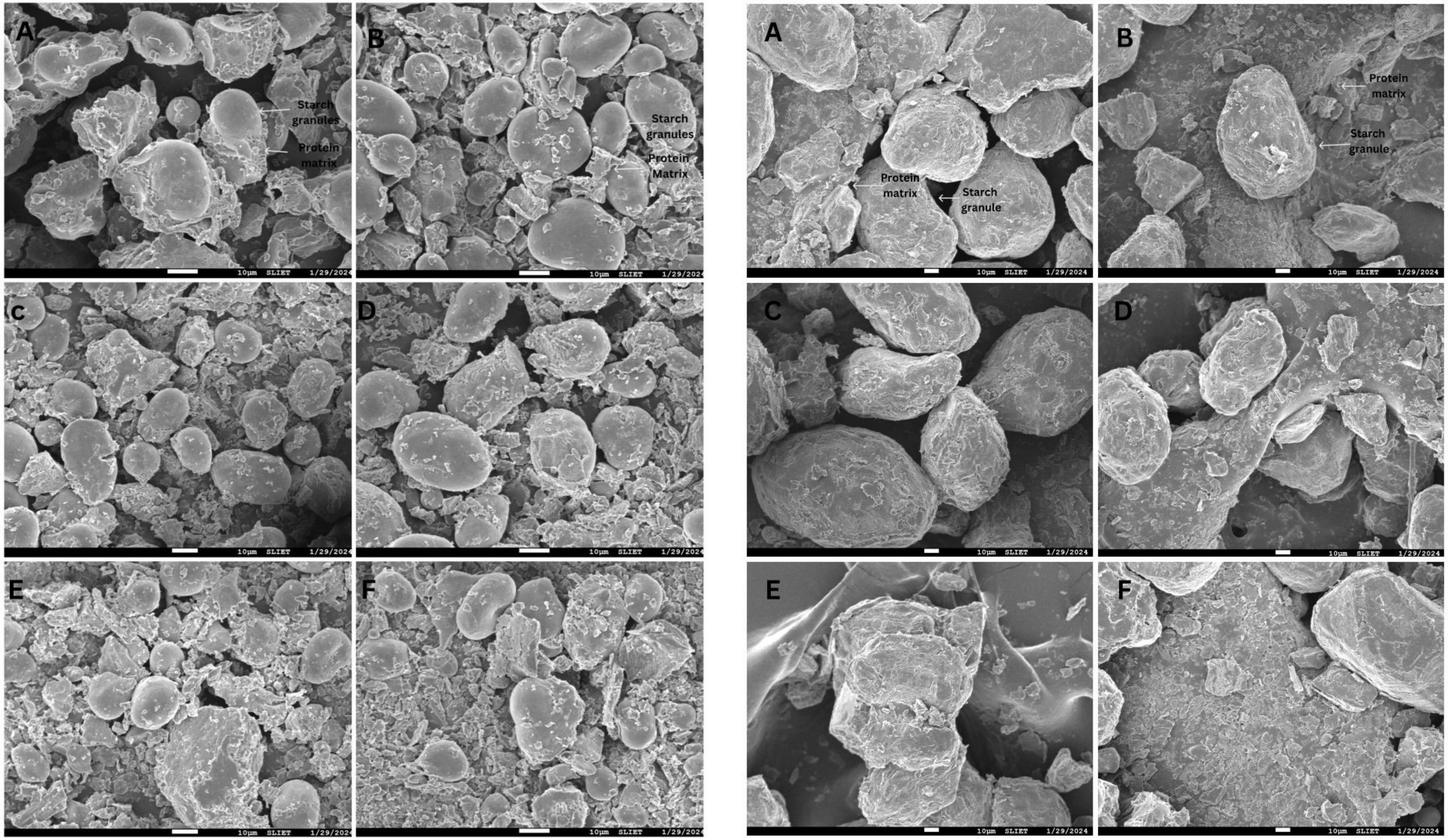


Fig. 2. Pasting curve of raw lentil flour samples. The samples were designated as WLF (Whole lentil flour), DLF (Dehulled lentil flour), SWLF (Soaked whole lentil flour), SDLF (Soaked dehulled lentil flour), GWLF (Germinated whole lentil flour), GDLF (Germinated dehulled lentil flour).



(i) (ii)

Fig. 3. Microstructure of lentil flour (a) RAW and (b) MAC with different pretreatments and their combinations as A. WLF, B. DLF, C. SWLF, D. SDLF, E. GWLF, F. GDLF. The samples were designated as WLF (Whole lentil flour), DLF (Dehulled lentil flour), SWLF (Soaked whole lentil flour), SDLF (Soaked dehulled lentil flour), GWLF (Germinated whole lentil flour), GDLF (Germinated dehulled lentil flour).

Table 1. Effect of dehulling, soaking, and germination on proximate composition (on dry weight basis) of raw and MAC lentil flour

Pretreatment		Moisture (%)	Protein (%)	Fat (%)	Crude fiber (%)	Ash (%)	Carbohydrate (%)
Raw	WLF	8.33 ± 0.08^{fg}	26.68 ± 0.18^{efg}	1.38 ± 0.07^{ab}	1.67 ± 0.04^{e}	3.61 ± 0.18^{a}	58.33 ± 0.68^{ab}
	DLF	8.49 ± 0.05^{efg}	28.75 ± 0.14^{bc}	1.52 ± 0.06^{a}	1.05 ± 0.27^{g}	3.43 ± 0.10^{a}	56.76 ± 0.32^{abc}
	SWLF	8.24 ± 0.03^{g}	27.13 ± 0.17^{def}	1.34 ± 0.05^{ab}	1.71 ± 0.05^{e}	3.57 ± 0.12^{a}	58.01 ± 0.31^{abc}
	SDLF	8.27 ± 0.05^{g}	28.97 ± 0.25^{b}	1.47 ± 0.07^{a}	1.13 ± 0.13^{fg}	3.39 ± 0.34^{a}	56.77 ± 0.91^{abc}
	GWLF	9.59 ± 0.13^{b}	29.02 ± 0.32^{b}	1.29 ± 0.22^{abc}	3.84 ± 0.33^{b}	3.21 ± 0.04^{a}	53.41 ± 1.07^{de}
	GDLF	10.04 ± 0.22^{a}	30.91 ± 0.19^{a}	1.40 ± 0.04^{a}	2.96 ± 0.04^{c}	3.18 ± 0.16^{a}	51.51 ± 0.89^{e}
MAC	WLF	8.61 ± 0.07^{def}	25.90 ± 0.27^{g}	0.96 ± 0.21^{cd}	2.39 ± 0.20^{d}	3.35 ± 0.08^{a}	58.79 ± 0.67^{a}
	DLF	8.81 ± 0.09^{d}	27.58 ± 0.35^{de}	1.03 ± 0.05^{bcd}	1.47 ± 0.12^{efg}	3.21 ± 0.30^{a}	57.90 ± 0.81^{abc}
	SWLF	8.69 ± 0.04^{de}	25.88 ± 0.27^{g}	0.89 ± 0.24^{d}	2.43 ± 0.07^{d}	3.21 ± 0.07^{a}	58.90 ± 1.17^{a}
	SDLF	8.64 ± 0.12^{de}	27.61 ± 0.46^{de}	0.97 ± 0.03^{cd}	1.51 ± 0.05^{ef}	3.17 ± 0.14^{a}	58.71 ± 0.51^{a}
	GWLF	9.19 ± 0.14^{c}	26.55 ± 0.55^{fg}	0.74 ± 0.05^{d}	4.32 ± 0.13^{a}	3.15 ± 0.04^{a}	56.05 ± 1.14^{bc}
	GDLF	8.82 ± 0.10^{d}	27.98 ± 0.23^{cd}	0.82 ± 0.04^{d}	3.61 ± 0.05^{b}	3.11 ± 0.18^{a}	55.66 ± 1.03^{cd}

Data is represented as mean ± standard deviation. Means sharing different superscript letters within the same column differ significantly ($p < 0.05$) as per two-way ANOVA followed by post-hoc Tukey test.

WLF – whole lentil flour, DLF – dehulled lentil flour, SWLF – soaked whole lentil flour, SDLF – soaked & dehulled lentil flour, GWLF – germinated whole lentil flour, GDLF – germinated & dehulled lentil flour.

Table 2. Effect of dehulling, soaking, and germination on technofunctional properties of raw and MAC lentil flour

Pretreatment		**WAC (g water/g flour)**	**OAC (g oil/g flour)**	**EC (%)**	**FC (%)**
Raw	WLF	0.88±0.08^{e}	0.93±0.08^{h}	44.45±0.93^{k}	15.06±0.21^{f}
	DLF	1.02±0.07^{de}	1.31±0.11^{g}	72.33±0.69^{f}	17.36±0.35^{d}
	SWLF	0.91±0.04^{e}	1.12±0.03^{h}	52.08±0.92^{j}	15.78±0.19^{e}
	SDLF	1.17±0.08^{d}	1.33±0.04^{g}	78.04±0.90^{de}	18.41±0.82^{c}
	GWLF	1.12±0.23d^{e}	1.81±0.09^{e}	64.78±1.12^{g}	19.55±0.35^{b}
	GDLF	1.26±0.05^{d}	2.13±0.05^{d}	88.3±1.24^{b}	21.37±0.39^{a}
MAC	WLF	1.78±0.04^{c}	1.53±0.04^{f}	57.88±1.17^{i}	10.33±0.61^{i}
	DLF	1.82±0.05^{c}	1.93±0.03^{e}	78.95±0.79^{d}	10.51±0.79^{i}
	SWLF	1.92±0.04^{c}	2.43±0.04^{c}	61.38±1.15^{h}	10.86±1.15^{hi}
	SDLF	2.23±0.08^{b}	2.53±0.02^{bc}	83.66±0.91^{c}	11.25±0.91^{h}
	GWLF	2.42±0.04^{b}	2.68±0.04^{b}	75.43±1.07^{e}	11.83±1.07^{gh}
	GDLF	2.92±0.07^{a}	2.91±0.05^{a}	94.11±1.11^{a}	12.22±1.11^{g}

Data is represented as mean ± standard deviation. Means sharing different superscript letters within the same column differ significantly ($p < 0.05$) as per two-way ANOVA followed by post-hoc Tukey test.

WLF – whole lentil flour, DLF – dehulled lentil flour, SWLF – soaked whole lentil flour, SDLF – soaked & dehulled lentil flour, GWLF – germinated whole lentil flour, GDLF – germinated & dehulled lentil flour.

WHC- Water holding capacity, OHC – Oil holding capacity, EC- Emulsifying capacity, FC-Foaming capacity.

Table 3. Effect of dehulling, soaking, and germination on antinutritional factors and bioactive properties of raw and MAC lentil flour

Pretreatment		Phytic acid (mg/g dw)	Tannin (mg CE/g dw)	Trypsin inhibitor activity (TIU/mg dw)	TPC (mg GAE/g)	DPPH Inhibition (%)
Raw	WLF	10.8 ± 0.23^{a}	7.53 ± 0.29^{a}	4.69 ± 0.27^{a}	7.87 ± 0.29^{a}	35.37 ± 1.79^{a}
	DLF	5.5 ± 0.21^{c}	1.26 ± 0.08^{ef}	3.17 ± 0.11^{b}	3.87 ± 0.16^{c}	28.82 ± 1.12^{bc}
	SWLF	8.1 ± 0.47^{b}	4.42 ± 0.16^{b}	2.02 ± 0.10^{d}	6.12 ± 0.11^{b}	31.94 ± 1.09^{b}
	SDLF	4.2 ± 0.18^{d}	0.83 ± 0.12^{fg}	1.29 ± 0.07^{e}	3.71 ± 0.14^{c}	22.99 ± 1.15^{d}
	GWLF	2.9 ± 0.25^{e}	2.98 ± 0.18^{d}	1.13 ± 0.05^{ef}	$2.25\pm0.16d^{e}$	27.15 ± 02.08^{c}
	GDLF	1.6 ± 0.09^{fg}	0.43 ± 0.07^{gh}	0.84 ± 0.09^{f}	1.97 ± 0.09^{e}	16.96 ± 1.11^{ef}
MAC	WLF	4.2 ± 0.42^{d}	3.67 ± 0.14^{c}	0.29 ± 0.05^{g}	3.62 ± 0.12^{c}	19.69 ± 2.06^{de}
	DLF	2.3 ± 0.72^{ef}	0.60 ± 0.17^{gh}	0.21 ± 0.08^{g}	1.87 ± 0.18^{e}	14.95 ± 1.07^{fgh}
	SWLF	2.7 ± 0.49^{e}	2.82 ± 0.11^{d}	0.17 ± 0.04^{c}	2.62 ± 0.14^{d}	16.72 ± 1.11^{efg}
	SDLF	1.2 ± 0.27^{g}	0.36 ± 0.13^{h}	0.12 ± 0.07^{c}	1.12 ± 0.08^{f}	12.78 ± 1.46^{gh}
	GWLF	1.0 ± 0.17^{g}	1.57 ± 0.16^{e}	0.11 ± 0.04^{g}	0.92 ± 0.09^{fg}	13.38 ± 0.94^{fgh}
	GDLF	0.6 ± 0.06^{g}	0.19 ± 0.09^{h}	0.06 ± 0.03^{g}	0.55 ± 0.07^{g}	11.75 ± 0.56^{h}

Data is represented as mean ± standard deviation. Means sharing different superscript letters within the same column differ significantly ($p < 0.05$) as per two-way ANOVA followed by post-hoc Tukey test.

WLF – whole lentil flour, DLF – dehulled lentil flour, SWLF – soaked whole lentil flour, SDLF – soaked & dehulled lentil flour, GWLF – germinated whole lentil flour, GDLF – germinated & dehulled lentil flour.

dw – dry weight, CE – Catechin equivalent, TIU – Trypsin Inhibitor unit, GAE – Gallic acid equivalent, DPPH - 2,2-diphenyl-1-picrylhydrazyl.

Table 4. Effect of dehulling, soaking, and germination on pasting properties of raw and MAC lentil flour

Pretreatment		**Peak viscosity (cP)**	**Trough viscosity (cP)**	**Breakdown viscosity (cP)**	**Final viscosity (cP)**	**Setback viscosity (cP)**	**Peak time (min)**	**Pasting temperature (°C)**
Raw	WLF	798±24^{c}	705±17^{d}	93±3.34^{a}	1009±39^{c}	304±9.22^{d}	5.13±0.12^{a}	76.65±4.21^{a}
	DLF	900±12^{b}	844±21^{b}	56±1.05^{c}	1216±24^{b}	372±7.31^{c}	5.6±0.10^{a}	77.45±3.11^{a}
	SWLF	840±30^{c}	770±16^{c}	70±2.17^{b}	1214±21^{b}	444±11^{b}	7±0.66^{a}	79.85±0.93^{a}
	SDLF	1366±47^{a}	1299±39^{a}	67±1.03^{b}	1800±50^{a}	501±13^{a}	7±0.20^{a}	79.05±0.89^{a}
	GWLF	430±12^{e}	410±19^{f}	20±0.83^{e}	586±14^{d}	176±5.2^{e}	7±0.32^{a}	79.9±0.79^{a}
	GDLF	497±16^{d}	485±13^{e}	12±0.79^{f}	648±18^{d}	163±8.2^{e}	6.8±0.41^{a}	80.75±1.68^{a}
MAC	WLF	22±4.55^{g}	20±3.70^{h}	2±0.32^{g}	35±5.66^{f}	15±7.22^{g}	6.86±2.23^{a}	nd
	DLF	27±6.2^{g}	25±5.61^{h}	2±0.44^{g}	41±5.98^{f}	16±4.34^{g}	6.53±1.98^{a}	nd
	SWLF	27±9.21^{g}	25±2.66^{h}	2±0.27^{g}	48±6.34^{f}	23±5.20^{g}	6.73±2.43^{a}	nd
	SDLF	67±7.11^{fg}	59±8.17^{gh}	8±0.67^{fg}	153±9.87^{e}	94±11^{f}	7±3.11^{a}	nd
	GWLF	28±6.34^{g}	26±7.32^{h}	2±0.29^{g}	49±4.76^{f}	23±7.6^{g}	6.67±1.87^{a}	nd
	GDLF	114±14^{f}	81±11^{g}	33±7.32^{d}	86±3.56^{f}	5±1.76^{g}	6.73±3.43^{a}	nd

Data is represented as mean ± standard deviation. Means sharing different superscript letters within the same column differ significantly ($p < 0.05$) as per two-way ANOVA followed by post-hoc Tukey test.

WLF – whole lentil flour, DLF – dehulled lentil flour, SWLF – soaked whole lentil flour, SDLF – soaked & dehulled lentil flour, GWLF – germinated whole lentil flour, GDLF – germinated & dehulled lentil flour.

nd: Not defined (No pasting temperature observed as they were already gelatinized)

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Data availability

The data will be made available from the corresponding author upon reasonable request.