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Farinographic Properties of Germinated Lentils and Wheat Flour Blends

Annalisa Romano*, Federica Cirrincione, Mariagrazia Naclerio, Lucia De Luca, Raffaele Romano

Dipartimento di Agraria, Università di Napoli FEDERICO II, Piazza Carlo di Borbone, 80055, Portici (NA), Italy
annalisa.romano@unina.it

Given its excellent and balanced nutritional composition, particularly as a high source of proteins, lentil (*Lens culinaris Medik.*) flour is now being increasingly blended with wheat flour to produce different types of bakery products, such as bread. This study explored the potential use of germinated lentil flour blended with wheat flour (WF) for bread-making, using farinographic analysis. WF was partially replaced with 0 %, 20 %, and 30 % of non-germinated lentil flour (LF) and germinated LF for 24 hours (LF24) and 48 hours (LF48). Microstructure and particle size, examined through SEM and sieve analysis, revealed more significant particle agglomeration in lentil flour samples than WF, with WF and LF showing monomodal and similar size distributions, while LF24 and LF48 displayed bimodal patterns. Farinographic analysis indicated increased germination time and LF concentration decreased water absorption capacity. Dough development time increased, whereas stability time and elasticity varied significantly depending on LF type and substitution rate. Overall, lentil germination proved a practical method for improving crucial technological properties in breadmaking. These findings support the formulation of innovative products using germinated lentil flour, combining enhanced nutritional profiles with high-quality processing standards.

1. Introduction

Bread made from wheat flour is a staple food in many countries and a major source of carbohydrates in European diets. Nutritionally, wheat has a relatively low level of protein (7 % -15 %) (Portman et al., 2018) when compared to the protein content of other foods, such as lentils (*Lens culinaris Medik*). Thus, the new bread-making trends focus on developing functional bakery products that satisfy new consumers' requirements for a healthy and sustainable diet, using different functional ingredients, i.e., lentils or germinated flours (Romano et al., 2024). Lentils are a promising option due to their nutritional benefits, particularly for vegetarian and vegan diets. Lentil-based composite flour could be more affordable and offer a convenient way to boost the nutritional value of foods. Germination is a traditional and inexpensive green method involving chemical changes such as the hydrolysis of starch, protein and fat by amylolytic, proteolytic and lipolytic enzymes (Dragomir et al., 2025). When seeds are hydrated (soaked) and then held (sprouted) under ambient conditions (20 – 25 °C), both endogenous and newly synthesised enzymes begin to modify seed constituents and, consequently, their properties (Romano et al., 2021). The germination time and temperature are, among others, the most critical factors influencing sprouted seeds' nutritional quality and properties (Avezum et al., 2023). However, the impact of different ratios in wheat-based bread of lentil and germinated lentil flour has not been fully explored. Then, this study was conducted to determine the potential use of germinated lentil flour and wheat flour blends for breadmaking through farinographic analysis. Since the farinograph is one of the most critical analyses of flours to evaluate their baking quality, Wheat flour (WF) was partially replaced with different concentrations (0, 20 and 30 %) of germinated lentil flours—LF (0 hours), LF24 (24 hours) and LF48 (48 hours) and the main properties were evaluated.

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2. Materials and Methods5

2.1 Materials

Lentil seeds (*Lens culinaris Medik.*), having an average mass of 0.03 ± 0.003 g and a diameter of 4.38 ± 0.14 mm, were gifted by producers (Terre di Altamura, Bari, Apulia, Italy) from the 2021 crop year harvest (Bari, Italy). Wheat flour (WF) was supplied by Mulino Caputo (Antimo Caputo Srl, Naples, Italy).

2.2 Preparation of germinated samples

Lentil seeds were washed with 0.07 % (w/v) sodium hypochlorite solution for 30 min at room temperature and then rinsed with deionised water several times until they reached a neutral pH. Afterwards, they were soaked overnight in distilled water following a 1:3 (w/v) ratio in a dark chamber under controlled temperature (22 – 24 °C). The morning after, water was drained, and the hydrated seeds were placed in the dark and covered by a wet cloth to germinate for 24 and 48 hours. The sprouted seeds were oven-dried at 60 °C for 17–18 h. The rootlets and hulls were removed, and the germinated samples were packed in polypropylene airtight containers and stored at 4 ± 3 °C.

2.3 Milling lentil seeds

Lentil seeds - raw (LF) and germinated for 24 h (LF24) and 48 h (LF48) - were milled into flour samples using a Laboratory mill (mod. 3100, Perten instruments Ab, Finland) and then sifted to obtain a particle size < 425 µm (Giuliani sifter, Turin, Italy). The flour samples were packed in polypropylene airtight containers at 4 ± 3 °C.

2.4 Flour microstructural analysis

Each flour (WF, LF, LF24, and LF 48) was dried at the critical point and coated with gold particles. Scanning electron microscopy (SEM) (LEO EVO 40, Zeiss, Germany) was used to examine the samples' microstructure with a 20 kV acceleration voltage and a magnification of ×2K.

2.5 Particle size distribution

The particle size analysis used to determine the distribution of flour samples was determined following Mirza Alizadeh et al. (2020). Approximately 100g of flour was placed in a stack of five progressively finer mesh sieves (53 µm, 106 µm, 150 µm, 224 µm, 300 µm). The separation was carried out using a vibrating screen machine (Octagon 200, Endecotts, English) for 10 minutes. The particle distribution was calculated as the percentage of separated fractions over the total.

2.6 Chemical properties of samples

The moisture content of each sample was achieved following the AACC International method (number 44-15.02, AACC International, 1999).
Total starch (TS) (g/100g) was determined using an enzymatic assay kit (Total Starch Assay Kit, Megazyme International Ireland) by the AACC method (number 76.13, 2009).
The total protein content was measured using the Kjeldahl method by determining the total nitrogen. A conversion factor of N × 6.25 was used to translate the nitrogen content into protein content (Romano et al., 2024).

2.7 Farinographic study

The doughs were prepared by mixing flour (WF and LF, WF and LF24 or WF and LF48) and ultra-pure water using a Brabender farinograph (Type AT, Brabender OHG, Duisburg, Germany). The water added to each dough at each mixing rate (0, 20 and 30 %) was held constant based on the required volume to combine with the flour to reach a consistency value between 500 ± 15 Brabender Units (BU).
The water absorption capacity (WAC, water absorption at the maximum consistency), dough development time (DDT, time to reach maximum consistency, in minutes), elasticity (bandwidth of the curve at maximum consistency, in BU), Brabender stability (time dough consistency remains at 500 BU) and Mixing Tolerance Index (MTI, consistency difference between height at pick and that 5 min later) were also determined.

2.8 Statistical analysis

All experiments were performed in triplicate, and data were expressed as mean values ± SD. Statistical analyses were performed using SPSS version 19.0 (SPSS Inc., Chicago, IL, USA). Analysis of variance was carried out on the data gathered from the different evaluations. Significant differences between the detected parameters were compared by Duncan's multiple comparison test at the 95% confidence level ($p \leq 0.05$) and are expressed as a different letter within a row.

3 Results and Discussion

3.1 Microstructure and particle size of flour samples

The morphological structure of WF, LF, LF24 and LF48 samples were observed through scanning electron microscopy (SEM) and reported in Figure 1.

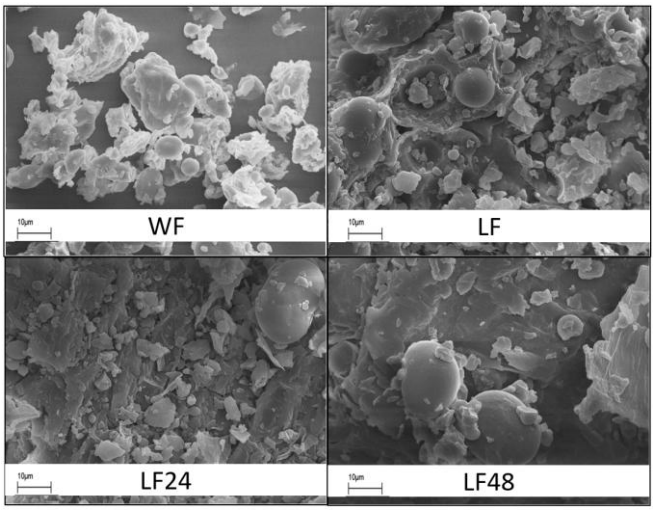

Figure 1: Scanning electron micrographs of flour samples: WF, LF, LF24 and LF48 at x 2000

The SEM images in Figure 1 revealed that germinated samples (LF24 and LF48) exhibited microstructural features similar to the LF, including starch granules embedded within a protein matrix. The starch granules in lentil samples maintained an oval shape with heterogeneous sizes, measuring approximately 10–30 µm in length and 10–20 µm in width, and displayed smooth surfaces, often with remnants of protein clusters and/or fibre fragments attached. The protein body granules, ranging from ovoid to spherical shapes, were consistently more minor than the starch granules, aligning with Błaszczak et al. (2007), who stated that germination introduced distinct microstructural changes. These included reducing the number of intact starch granules, their detachment from the surrounding protein and fibre networks, and the appearance of free protein wedges within the flour matrix. These structural modifications are generally critical because they can directly impact various functional properties of the flour, including in vitro starch digestibility. As for WF flour, large protein bodies were observed alongside small starch granules (<10 µm), following what Lindeboom et al. (2004) and Ma et al. (2021) already reported.

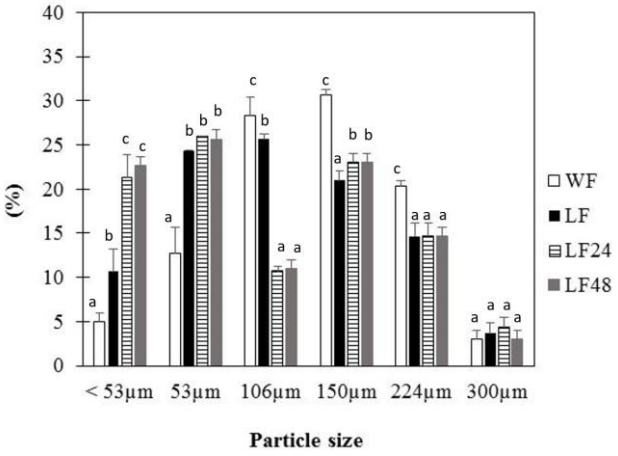

Figure 2: Particle size distribution (%) of WF (□), LF (■), LF24 (▒), LF48(▉).

The particle size distribution, shown in Figure 2, exhibited distinct patterns since WF and LF showed monomodal distributions with peaks at 150 µm and 106 µm, respectively, while LF24 and LF48 displayed

similar bimodal distributions, having two distinct populations below and above 106 µm. In particular, WF had a higher percentage of larger particles (106 – 150 µm) compared to lentil flours, while LF and the germinated ones showed more particles in the smaller size ranges (53 µm and < 53 µm), indicating finer milling or the breakdown of particle structures during germination. The reduction in more significant particle fractions for LF24 and LF48 suggests that germination and subsequent milling might have enhanced the disintegration of lentil seed structures (Thakur et al., 2019).

3.2 Chemical properties of flour samples

Chemical properties of flour samples strongly influence dough formation, texture, bakery product quality and flour applications. Table 1 shows the moisture content, Total Starch (TS), and protein content of WF, LF, LF24 and LF48 samples.

Table 1: Physicochemical properties of WF, LF, LF24 and LF48 samples.

Parameters	WF	LF	LF24	LF48
Moisture content (%)	10.04 ± 0.24c	7.71 ± 0.51a	7.91 ± 0.57a	8.90 ± 0.31b
TS (% d.m.)	77.19 ± 0.84c	34.83 ± 0.82b	32.95 ± 0.19a	32.89 ± 0.53a
Protein content (% d.m.)	14.47 ± 0.23a	21.19 ± 0.51b	25.88 ± 0.98c	26.87 ±0.01c

Means followed by a different letter within a row are significantly different ($p < 0.05$)

The analysis showed that wheat flour (WF) had a higher moisture content (10.0 %) compared to lentil flour (LF) and germinated lentil flour (LF24 and LF48), which ranged from 7.7 % to 8.9 %. The results aligned with Xu et al. (2019), which demonstrated how germination modifies the chemical structure of macronutrients, leading to higher water absorption and, consequently, higher moisture content.

The total starch of lentil flour samples tended to decrease as a function of germination time, with values ranging from 34.8 ± 0.8 % for LF to 32.9 ± 0.5 % for LF48. With the increase of amylase activity due to germination, which hydrolyses amylose and amylopectin into destrins and maltose, a decrease is expected in the total starch content (Chinma et al., 2022). Also, it increased the degree of damaged starch, which caused a high affinity for water molecules.

Germination increased the protein content from 21.2 ± 0.5 % for LF to 26.9 ± 0.0 % for LF48 samples (Atudorei et al., 2021). This increase was attributed to various factors, such as the synthesis of proteolytic enzymes, which resulted in the degradation of proteins into simple peptides. The germination of lentils leads to the degradation of proteins with increased peptides with many polar groups (Atudorei et al., 2021).

3.3 Farinographic properties of the doughs

The farinographic properties of dough provide essential insights into the rheological behaviour of dough and gluten network strength, which are critical factors influencing the processing performance and end-product quality in baking and other food applications. Figure 3 (a-d) shows the farinographic properties of WF doughs having different LF contents (0, 20, 30 %) and lentil flour types (LF, LF24 or LF48).

WF exhibited the highest water absorption capacity (WAC) among the samples (figure 3 a), reaching 62.9 ± 0.1 %. In the 20% and 30% substitution doughs, LF demonstrated a higher ($p < 0.05$) WAC than LF24 and LF48, respectively. The lowest recorded WAC was 58.8 ± 0.2 % for LF48 at 30 % substitution. Furthermore, an increased concentration determined a decrease in WAC for each type of lentil flour used, especially for LF48. This may be ascribable to the lower TS and absolute protein content due to the germination that caused a diminish in WAC (Atudorei et al., 2021; Xu et al., 2019).

Dough Development Time (DDT) results (Figure 3 b) showed a general delay in dough structurisation. LF-substituted doughs didn't show any relevant differences among themselves, while LF24 and LF48 showed significant ($p < 0.05$) increase in DDT when the 30 % was added, with values of 6.3 ± 0.1 minutes for LF24 and 7.2 ± 0.1 minutes for LF48. These results aligned with the WAC findings, as lower WAC delays network formation, consequently slowing down dough development. Furthermore, the prolonged germination time and enzymatic activity alter the formation of the dough, thus causing a delay in the DDT (Atudorei & Codină, 2020). Regarding stability time (Figure 3 c), a 20 % addition of lentil flour reduced it from 16.9 ± 2.1 minutes to 10.0 ± 0.0 minutes. However, further LF, LF24, or LF48 increased the stabilization the doughs. At 20% substitution, the stability time of LF48 was significantly lower ($p < 0.05$) compared to LF and LF24. However, at 30 % substitution, the dough exhibited increased stability. The addition of germinated flours could lead to weaker doughs due to less starch and protein content, as reported by Hallén et al. (2004) in their study.

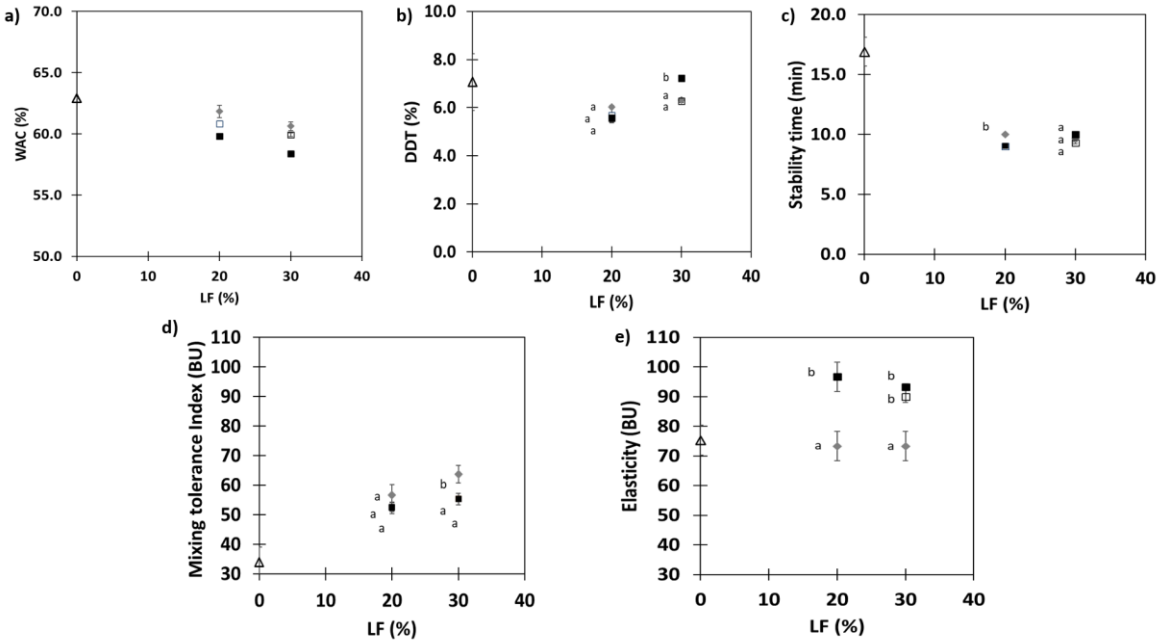

Figure 3: Farinographic analysis results of WF (Δ), LF (◆), LF24 (□) and LF48 (■) doughs at different WF substitution ratios: Water absorption capacity (WAC), Dough development time (DDT), Stability time, Mixing Tolerance Index and Elasticity.

Regarding the Mixing Tolerance Index (MTI), there was a significant increase ($p < 0.05$) as the percentage of wheat flour decreased for all samples (Figure 3 d). In particular, LF24 and LF48 were similar but differed significantly ($p < 0.05$) from the control when the 30 % was added. The presence of LF (%), a lower protein content, and the loss of starch during germination may have conflicting effects on water absorption, hydration and resistance of the dough to any strain and, thus, on the degree of softening (Millar et al., 2019).
Finally, the elasticity of the doughs exhibited different behaviours (Figure 3 e). WF and LF showed similar stabilised patterns, likely due to their comparable particle size distribution (Figure 2), which indicated a higher percentage of particles with larger volumes in both flour samples. In contrast, LF24 and LF48 displayed significantly higher elasticity values ($p < 0.05$) at both substitution levels, ranging from 96.7 to 90.0 BU. This increase could be attributed to the interaction between lentil flour proteins and WF gluten (Kohajdová et al., 2013), which competed for water and influenced its distribution, as well as the higher percentage of finer particles in these two flour samples (Kotsiou et al., 2023).

4. Conclusions

Farinograph results played a crucial role in assessing the dough behavior, revealing that increasing germination time and lentil flour concentration reduced water absorption capacity and delayed dough development and gluten network formation, impacting mixing tolerance and dough flexibility. This study demonstrated that germinated lentil flour can be effectively blended with wheat flour for bread-making, improving the nutritional profile of one of the most important staple foods.
Germinated lentil flour presents a promising approach to developing functional bakery products with enhanced protein content and technological properties.

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