ORIGINAL ARTICLE

Food Chemistry, Engineering, Processing and Packaging

Evaluation of Technological Performance of Algerian Soft Wheat Varieties

Lynda Messaoudene [1] ✉ Amina Belguendouz [2] Lamia Medouni-Haroune [1] Samira Negrichi [1] Mohamed Khalil Mellal [1]

1 Centre de Recherche en Technologies Agro-Alimentaires Route de Targa Ouzemmour, Campus Universitaire, Bejaia, 06000, Algeria. lynda.messaoudene@crtaa.univ-bejaia.dz / lamia.madouni@crtaa.univ-bejaia.dz / samira.negrichi@crtaa.univ-bejaia.dz / khalil.mellal@crtaa.univ-bejaia.dz

2 Laboratoire d'analyse et contrôle de qualité et de conformité AMINA LABO, Elmeniaa. Algeria. amina_labo@yahoo.com

ABSTRACT

Background: Soft wheat (*Triticum aestivum* L.) constitutes the third most cultivated cereal crop in Algeria, following barley and durum wheat.

Aims: This study was conducted to perform a comparative evaluation of technological performance between local common wheat varieties and newly developed experimental lines. The primary objective was to assess the differences in their quality attributes and predict their potential suitability for a broader range of flour-based industrial applications.

Methods: Nineteen Algerian wheat samples, comprising 13 local varieties and 6 test lines, were milled and analyzed for their fundamental technological quality parameters. Flour characteristics, including protein content, gluten content, Zeleny sedimentation values, and Alveograph parameters were subjected to correlation analysis, multivariate statistics, and hierarchical clustering for comprehensive evaluation.

Results: The flour extraction rates ranged from 60.9% to 77.3%, with no significant statistical difference observed between the local varieties and test lines. Zeleny sedimentation values fluctuated between 22.17 and 34.67 mL, allowing for a quality classification spanning from medium to very good. The varieties exhibited a broad spectrum of technological quality, with dough strength values (W) ranging from 103 to 277 × 10^{-4} J. On average, the experimental lines demonstrated significantly higher W values, indicating superior dough strength compared to the local varieties. Based on the Tenacity/Extensibility ratio, five varieties were considered suitable for the milling sector, while six were identified as potentially ideal for bread-making. Furthermore, the test lines also exhibited higher tenacity, reinforcing their potential for stronger dough formulations. While thirteen varieties exhibited high protein content, and test lines displayed superior gluten quality, ten varieties did not meet the acceptable minimum standards for wet gluten, six failed for dry gluten, and fifteen were deficient in extensibility. However, no significant differences were observed between the local varieties and test lines in terms of extensibility and dough volume.

Conclusions: Although none of the studied samples fully satisfied the stringent industrial specifications for premium bread or noodle production, several varieties displayed promising dough strength properties. The varieties with lower overall quality may still be suitable for less demanding applications, such as biscuits, cakes, or traditional local baked goods.

Keywords: *Triticum aestivum* L.; Flour Quality; Dough Rheology; Alveograph Testing.

ARTICLE INFORMATION

✉ **Corresponding author:** Lynda Messaoudene
E-mail: lynda.messaoudene@crtaa.univ-bejaia.dz / lyndamessaoudene1@gmail.com
Tel. +213 796 227 512

Received: January 06, 2024
Revised: August 25, 2025
Accepted: August 28, 2025
Published: September 28, 2025

Article edited by:
Prof. Khaled Méghit Boumediene
Article reviewed by:
Dr. Hayet Ben Haj Koubaier
Dr. Fatma Boukid
Dr. Imen Falfoul

Cite this article as: Messaoudene L., Belguendouz A., Medouni-Haroune L., Negrichi S., & Mellal M.K. (2025). Evaluation of Technological Performance of Algerian Soft Wheat Varieties. *The North African Journal of Food and Nutrition Research, 9* (20): 181 – 192. https://doi.org/10.51745/najfnr.9.20.181-192

1 INTRODUCTION

Wheat stands as a cornerstone of global food security, providing approximately 20% of total dietary calories and essential nutrients to over 35% of the world's population (Sirat, 2022; Chakrabarti-Bell *et al.*, 2021). As the world's most widely cultivated cereal crop by area and second largest by production volume after maize, common wheat (*Triticum aestivum* L.) plays a critical role in meeting growing food demands. However, the quality characteristics of wheat varieties vary significantly across different growing regions and cultivars, making comprehensive quality assessment studies essential for optimizing agricultural productivity, ensuring food processing suitability, and maintaining nutritional standards in an era of increasing global food insecurity.

Algeria faces a critical challenge in wheat self-sufficiency, with its growing population expected to exceed 50 million by 2030 (Bessaoud, 2018). Despite being a significant regional producer of durum wheat, the country remains heavily dependent on imports, which supply approximately 70% of its domestic common wheat consumption. This dependency has intensified in recent years, with annual wheat imports averaging 7.6 million metric tons over the past five years and reaching 8.1 million metric tons in the 2022–23 marketing year—a 25% increase from the previous year and 7% above the five-year average (FAO, 2022). While Algeria's 263 flour mills efficiently process these imports into flour domestically (Bessaoud, 2018), the quality variability of both imported and locally produced wheat presents ongoing challenges for consistent flour and baking performance. Understanding the quality characteristics of Algeria's domestic wheat varieties is therefore crucial for optimizing local production, reducing import dependency, and ensuring food security for the nation's growing population.

Wheat quality assessment is fundamental to determining flour suitability for various baked goods, as the physicochemical properties of wheat directly influence the characteristics and processing behavior of the final products (Oikonomou *et al.*, 2015; Tozatti *et al.*, 2020). Critical quality parameters include protein content, gluten characteristics (wet and dry gluten), Zeleny sedimentation values, and rheological properties, which collectively determine flour performance in different baking applications (Rababah *et al.*, 2019). Among the various analytical methods available, the alveograph test has emerged as a particularly valuable tool for evaluating bread-making quality, providing crucial insights into dough strength, extensibility, and overall technological potential of wheat varieties (Indrani *et al.*, 2007; Jødal and Larsen, 2021). However, detailed comparative data on the technological quality of Algeria's most widely grown wheat varieties are still scarce, making it difficult for breeders and millers to select the best varieties for specific end-uses.

Although several studies have been conducted on Algerian common wheat, they remain limited in scope and coverage. Most focus either on the molecular biodiversity of Saharan bread wheat (Bellatreche *et al.*, 2019), the impact of climatic and environmental conditions on wheat production (Ouzani *et al.*, 2025), or their suitability for bread making (Abbes *et al.*, 2023). However, comprehensive comparative quality assessments that simultaneously evaluate both established local varieties and promising experimental breeding lines remain scarce in the literature. This knowledge gap is particularly significant given that many Algerian wheat genotypes are currently underutilized and often directed towards animal feed, representing a missed opportunity for valorization in human food applications. Additionally, the potential uses of these wheat resources beyond conventional bread making remain largely unexplored, limiting opportunities for product diversification and value addition in Algeria's wheat processing sector.

Given the critical importance of wheat quality assessment for optimizing domestic production, advancing breeding programs, and expanding processing applications, this study aimed to: (1) comprehensively evaluate the flour and dough quality of 19 common wheat varieties, including both established local varieties and experimental test lines, using standardized protocols for protein content, gluten parameters, Zeleny sedimentation, and alveograph analyses; (2) investigate interrelationships among quality traits through correlation and multivariate analyses to understand the underlying structure of quality variation; (3) compare quality performance between local varieties and test lines to assess breeding progress and identify superior genotypes; and (4) classify these varieties based on their technological properties to determine their suitability for different wheat flour-based applications and processing end-uses.

2 Materials and Methods

2.1 Sample Collection and Preparation

The study was conducted on 19 samples of Algerian common wheat (local varieties and lines under test) identified by simplified codes (V1 to V19) (Supplementary Table 1). The samples were obtained from the *Institut Technique des Grandes Cultures (ITGC)* located within *Oued Smar*, Algiers, in September 2013. The samples were then manually cleaned to remove all impurities (stones, insects, seeds of other species), weighed, and ground at the *Soummam* Mills Unit laboratory (ERIAD, *Sidi Aïch*, Béjaïa) using an experimental Brabender mill (Brabender Quadrumat® Senior, Duisburg, Germany).

2.2 Flours Characterizations

The resulting flour and bran were weighed to calculate the extraction rate, and then all flour samples were stored in airtight containers at a refrigeration temperature of 4 ± 1 °C until use. This was done to preserve their quality and prevent any contamination or moisture absorption that could affect the experimental. Samples were analyzed for moisture, protein content, gluten content, Zeleny sedimentation, and alveograph properties. Moisture content, gluten content, and Zeleny sedimentation were tested at the Soummam Mills Unit Laboratory (ERIAD Sidi Aich, Bejaia) using ISO 287, ISO 21415-3, and ISO 5529 methods, respectively. Protein content was analyzed using the Kjeldahl method, following the ISO 5983:1997 standard.

The Chopin-Alveograph test was performed in the Molino Grani unit laboratory (*Akbou*, Bejaia) with the use of an alveograph (Chopin NG, Villeneuve-la-Garenne, France) following the ISO5530/4 1992 standard. The equivalent of

250 g of flour was combined with the requisite amount of salt water, and the resulting dough was sheeted to the desired thickness before being cut into discs and set aside to rest. The produced dough discs were then inflated with air pressure into bubbles until they ruptured. The pressure fluctuation inside the bubbles was automatically recorded in a graph, allowing the following alveograph characteristics to be measured: the dough strength (W), tenacity (P), extensibility (L), dough swelling (G), alveograph ratio (P/L), and elasticity index (Ie).

2.3 Data Analysis

Descriptive statistics (mean ± standard deviation) were computed for each wheat flour variety across all selected parameters. Spearman correlation analyses were then performed twice: first on the full dataset to capture overall trait associations, and second within each variety category (local landraces vs. tested lines) to identify group-specific relationships. Correlation matrices were visualized as heatmaps, highlighting both global and within-group inter-parameter patterns. To test for multivariate differences in flour and dough quality profiles between categories, a permutational multivariate analysis of variance (PERMANOVA) was carried out using the "adonis2" function from the vegan package (Oksanen *et al.*, 2007). For univariate comparisons, each trait was subjected to the Kruskal–Wallis rank-sum test to detect significant differences among varieties. Pairwise comparisons were performed to identify which specific variety pairs differed for each parameter using Dunn's post-hoc test with Bonferroni correction using the dunn.test package (Dinno, 2023). Finally, hierarchical clustering was conducted on the same set of flour and dough quality variables. Prior to clustering, variables were standardized (z-score) using functions from the factoextra package (Kassambara & Mundt, 2017). A Euclidean distance matrix was computed, and Ward's linkage method was applied to generate dendrograms that visually group varieties according to their biochemical and functional trait similarities. All analyses were performed in R statistical software (version 4.1.1; R Development Core Team, 2024).

3 Results and Discussion

3.1 Overall Quality Parameter Distribution and Varietal Classification

The comprehensive analysis of 19 wheat varieties revealed variation in flour and dough quality parameters, with significant differences observed between local varieties and test lines across multiple quality traits (PERMANOVA: $F = 6.88$, $p = 0.008$). Statistical analysis using permutation-based multivariate analysis of variance demonstrated that varietal origin significantly influenced the overall quality profile, accounting for 11.1% of the total variation among samples (Table 1, Supplementary Table 2).

Table 1. Comparison of trait measurements between Local varieties and Test lines of wheat, showing means, standard deviations, ranges, and coefficients of variation (CV %). *P*-values shown represent post hoc test results adjusted using False Discovery Rate (FDR) correction

	Local varieties			Test Lines			
Trait	Mean ± SD	Range	CV %	Mean ± SD	Range	CV %	*p*-value
Moisture content %	15.90 ± 0.21	15.56–16.21	1.3	16.00 ± 0.37	15.29–16.46	2.3	0.291
ER %	71.31 ± 5.39	60.00–78.40	7.6	73.38 ± 1.68	70.00–76.80	2.3	0.097
Dry gluten %	8.51 ± 1.32	5.40–10.50	15.5	7.99 ± 0.48	7.00–9.00	6.0	0.106
Wet gluten %	24.17 ± 3.79	15.40–28.80	15.7	23.20 ± 1.81	20.00–26.80	7.8	1.000
Protein content (%)	11.13 ± 1.46	7.80–13.03	13.1	11.21 ± 0.59	9.70–12.04	5.3	0.783
Zeleny value (ml)	27.79 ± 3.63	22.00–34.00	13.0	31.21 ± 3.74	24.00–38.00	12.0	0.011
G (cm^3)	20.25 ± 4.43	10.00–26.50	21.9	19.32 ± 1.37	16.90–22.00	7.1	0.332
Ie (%)	44.85 ± 15.74	0.00–64.20	35.1	50.50 ± 7.83	38.20–61.50	15.5	0.162
L(mm)	86.36 ± 34.63	33.00–144.00	40.1	75.75 ± 11.20	58.00–100.00	14.8	0.179
P (mmH_2O)	68.15 ± 19.86	38.00–102.00	29.1	82.00 ± 16.35	46.00–106.00	19.9	0.022
P/L	1.03 ± 0.68	0.27–2.36	65.4	1.13 ± 0.32	0.50–1.57	28.4	0.551
W(10^{-4}J)	169.58 ± 39.26	100.00–250.00	23.1	205.42 ± 51.42	115.00–279.00	25.0	0.022

Note: ER: Extraction Rate; CV: Coefficients of Variation; G: Dough Swelling; Ie: Elasticity Index; L: Extensibility; P: Tenacity; P/L: Alveograph Ratio; W: Dough Strength.

Extraction Rate, Moisture Content, Protein Content and Gluten Characteristics

Extraction rates showed considerable variation among individual varieties, though no significant difference was observed between local varieties and test lines overall (71.31 ± 5.39% vs. 73.38 ± 1.68%, $p = 0.097$). The higher coefficient of variation in local varieties (7.6%) compared to test lines (2.3%) indicates greater diversity within the local germplasm. This pattern of higher variability in local varieties compared to test lines was observed across multiple traits, as illustrated in the distribution patterns shown in Figure 1. Moisture content remained consistently appropriate across all samples with minimal variation between groups (15.90 ± 0.21% vs. 16.00 ± 0.37%, $p = 0.291$), confirming proper grain conditioning prior to milling. The quality traits observed in

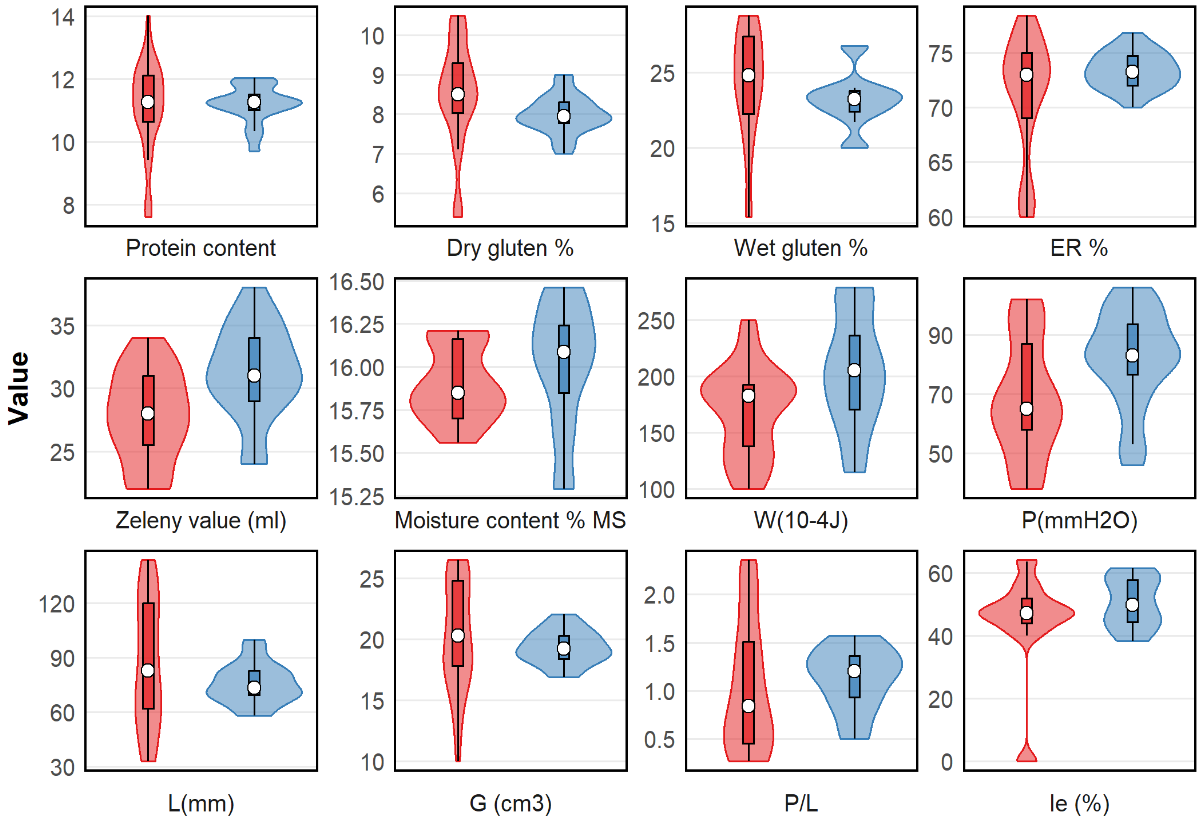

Figure 1. Violin plots comparing trait distributions between Local varieties (red) and Test lines (blue) of wheat

the 19 Algerian wheat varieties reveal both similarities and notable contrasts when compared to varieties from local, Mediterranean, and global wheat-producing regions (Table 2).

Among these traits, protein content shows particularly marked variation, ranging from 7.60% to 14.03% in local varieties and from 9.70% to 12.04% in the test lines. While the mean values did not differ significantly (11.13 ± 1.46% vs. 11.21 ± 0.59%; $p = 0.783$), the broader distribution among local varieties reflects a greater variability, which aligns closely

Table 2. Comparative quality parameters across global wheat-producing regions

Region	Protein %	Wet Gluten %	Dry Gluten %	Zeleny mL	W, ×10⁻⁴J	P/L	L mm	P mm	G	Ie	References
Algeria	7.6–14.0	20.00–26.80	5.4–10.5	22–38	103–277	0.5–2.36	33.00–144.00	38.00–106	10–22.00	00–64.20	This study
	9.20–12.18	20.27–32.88	<12	≤ 30	85–180	1.08–2.66	47.68–28.10	51.50–74.75	14.70–18.90	-	Abbes *et al.* (2023)
Mediterranean	10.7–14.4	-	-	-	178–262	0.41–1.23	68–138	55–95	-	-	Sakr *et al.* (2021), Iacovino *et al.* (2025), Karaduman *et al.* (2020) Iacovino *et al.* (2025) Blandino *et al.* (2016)
South Asia	10.5–16.5	19.41–41.77	6.7–16.5	164–422	-	-	-	-	-	-	Harisha *et al.* (2025) Chapla *et al.* (2017)
East Asia	11.2–14.1	17.70–37.9	-	-	210–396	-	-	-	-	-	Wang *et al.* (2025) Hu *et al.* (2025)
America	12.8–15.1	-	-	-	301–509	0.5–2.6	33.03–67.8	55.50–137.00	-	-	Hernández-Espinosa *et al.* (2018) Barros *et al.* (2022)
Australia	5.67–13.20	-	-	-	-	-	-	-	-	-	Kelly *et al.* (2025)

Note: CV: Coefficients of Variation.

with ranges reported for international wheat (Karaduman *et al.*, 2020; Iacovino *et al.*, 2025). This suggests that local genotypes hold considerable potential in terms of protein concentration. In contrast, the test lines remained up to 20% lower, indicating a performance gap likely attributable to genetic background.

Additional comparisons provide context for these findings (Table 2). Compared with Indian breeding lines (Harisha *et al.*, 2025), the local varieties demonstrated protein levels up to 35% higher, while the test lines were generally comparable or slightly lower. Similarly, when measured against previous studies on Algerian wheat (Abbes *et al.*, 2023), both groups showed an increase in protein content, with local varieties reaching up to 50% higher values, highlighting the influence of growing conditions and varietal potential.

Gluten-related parameters provide additional insights into the technological quality of the studied wheat varieties. Dry gluten content exhibited considerable variability, particularly among local varieties (CV = 15.5%) compared to test lines (CV = 6.0%). Local varieties showed a broader range (5.40–10.50%) than the test lines (7.00–9.00%), with no significant difference between group means (8.51 ± 1.32% vs. 7.99 ± 0.48%, p = 0.106). In terms of gluten content, neither group reached the levels typically observed in high-performing international varieties, reflecting their moderate classification (Harisha *et al.*, 2025; Wang *et al.*, 2025).

The Zeleny sedimentation index further supported these trends. Although a statistically significant difference was observed between local varieties and test lines (27.79 ± 3.63 ml vs. 31.21 ± 3.74 ml, p = 0.011) indicating superior gluten quality in the test lines (Figure 1), both groups showed lower values compared to the Indian genotype (Harisha *et al.*, 2025). Local varieties remained largely consistent with national values or slightly superior, confirming their intermediate performance (Abbes *et al.*, 2023).

Rheological properties

Alveograph analysis revealed significant differences in key rheological parameters between local varieties and test lines. Overall, the observed values align with a moderate gluten strength profile, supporting the previously observed trends.

Dough tenacity was significantly higher in test lines compared to local varieties (82.00 ± 16.35 mm H_2O vs. 68.15 ± 19.86 mm H_2O, p = 0.022), indicating stronger gluten networks. This pattern was reinforced by dough strength (W) measurements, which similarly favored test lines (205.42 ± 51.42 × 10^{-4} J vs. 169.58 ± 39.26 × 10^{-4} J, p = 0.022). Both parameters suggest that test lines possess more robust gluten structures with potential of withstanding processing stress. In contrast, dough extensibility (L) showed high variability, particularly in local varieties (CV = 40.1% vs. 14.8%), though group means did not differ significantly (86.36 ± 34.63 mm vs. 75.75 ± 11.20 mm, p = 0.179). Gas production parameters (G) similarly showed no significant differences between groups (20.25 ± 4.43 cm³ vs. 19.32 ± 1.37 cm³, p = 0.332), indicating comparable fermentation potential despite differences in gluten strength.

When contextualized against regional studies, test lines approached Lebanese wheat ranges for most parameters (Sakr *et al.*, 2021) and exceeded previous Algerian values by up to 34% (Abbes *et al.*, 2023), while both groups remained below Brazilian wheats levels. These findings collectively indicate that while test lines demonstrate improved gluten strength and consistency compared to local varieties, both groups exhibit moderate rheological properties when compared to international wheat varieties.

3.2 Inter-trait Correlations and Group-Specific Relationship Patterns

Correlation analysis revealed significant relationships among quality parameters, with distinctly different patterns observed between local varieties and test lines (Figure 2). Local varieties demonstrated stronger protein-rheology associations and more complex trait interdependence, while test lines showed more selective correlations and independent parameter behavior. Strong positive correlations were consistently observed between protein content and Zeleny sedimentation value across both groups (Local: r = 0.75, Test lines: r = 0.71, both p < 0.001), confirming the fundamental relationship between protein quantity and gluten quality assessment. Similar to our findings, Sirat (2022) reported that the Zeleny sedimentation value primarily depends on protein content, reflecting the test's measurement of gluten protein behavior in acidic conditions. This consistent relationship across both genetic groups validates the use of Zeleny sedimentation as a reliable protein quality indicator regardless of varietal background.

The relationship between protein content and dough strength observed in the present study indicates that protein content influences rheological behavior differently between groups. Local varieties showed stronger correlations between protein and dough strength (W), suggesting that protein quantity more reliably predicts functional properties in this genetic background. This contrasts with findings reported by (Bordes *et al.* 2008), who found no correlation between protein content and alveograph parameters. The discrepancy may reflect differences in genetic diversity and environmental conditions, as the broader genetic base in our local varieties may have created stronger protein-functionality relationships than those observed in more uniform commercial varieties.

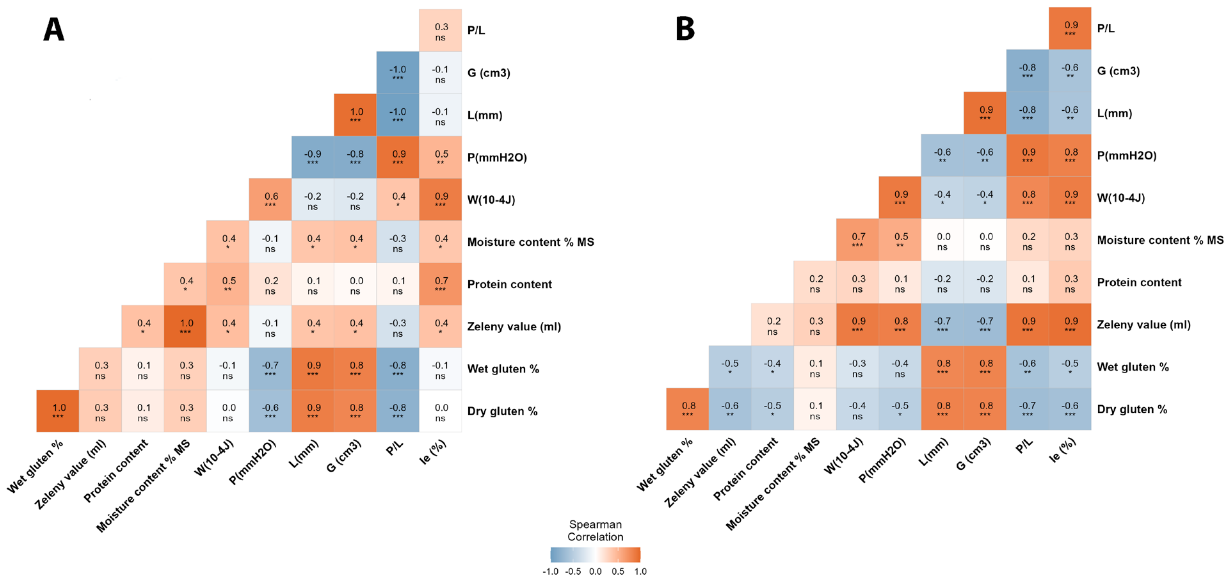

Figure 2. Correlation matrices of wheat flour quality parameters for (A) local varieties and (B) test lines. Spearman correlation coefficients are displayed in each cell, with significance levels indicated by color intensity and asterisks (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$)

Moderate correlations were detected between alveograph parameters W and P in both groups (Local: r ≈ 0.52, Test lines: r ≈ 0.48, both $p < 0.01$), indicating consistent interdependence of dough strength and tenacity across genetic backgrounds. This finding aligns with results reported by Jødal and Larsen (2021), who demonstrated a strong correlation between P and W, attributing it to the mathematical derivation of W from the alveograph curve area, which is directly influenced by curve height (P).

Strong negative correlations were found between extensibility (L) and the P/L ratio across both groups ($r < -0.6$, $p < 0.001$), reflecting the inherent inverse mathematical relationship between these rheological parameters. This relationship indicates that as dough extensibility increases, the balance shifts toward lower tenacity relative to extensibility, which is critical for determining optimal dough handling characteristics and end-use applications.

The most notable differences between variety groups were observed in correlations involving protein parameters and rheological properties, where local varieties consistently showed stronger associations compared to test lines. This pattern suggests different underlying genetic mechanisms governing dough behavior between the groups, with local varieties demonstrating more integrated protein-functionality relationships while test lines exhibit more independent trait expression. Previous research by Živančev *et al.* (2021) demonstrated that genotype significantly influences trait relationships in wheat, with certain parameters being more genotype-dependent than others. The distinct correlation patterns observed between our groups support this concept and indicate that selection strategies should be tailored to the specific genetic architecture of each population type.

3.3 Quality-Based Classification and End-Use Suitability Assessment

Soft wheat flour is widely used in products like bread, pasta, cakes, and cookies. Beyond these traditional uses, it also serves in thickened sauces and, through malting, it can yield natural sweeteners, texturizers, and thickeners that enhance bread quality and diversify its food applications (Calvi *et al.*, 2023; Khomych *et al.*, 2020; Meenu *et al.*, 2024). Depending on the intended end product, flour should meet specific requirements in terms of protein content and gluten strength (Table 3).

Individual variety analysis revealed significant differences among varieties for all measured parameters (Supplementary Table 2). For protein content, RMADA (V13) achieved the highest value (13.30 ± 0.66%), followed by ARZ (V3) (12.20 ± 0.07%) and AIN ABID (V2) (12.15 ± 0.12%), while Anapo (V19) exhibited the lowest protein content (7.80 ± 0.17%) ($\chi^2 = 51.81$, $p < 0.001$). The protein content required for wheat to be suitable for bread making is above 11% (Mut *et al.*, 2017). Based on this criterion,

varieties AIN ABID (V2), ARZ (V3), Ae-Squarrosa (Taus) Ben/4/Akla (V4), PASTOR (V5), DGA/BJY//FA*2

(V6), F94048GA-2/DELABRAD (V7), HXL7579/2BAU (V8), YANGMAI1/GEN/WOOO30 (V9), ANZA (V12), RMADA (V13), ANFORETA (V14), DJANATE (V16), and HD (V18) are considered the most potential for bread flour, as their protein content meets or exceeds the required threshold. However, HIDHAB (V1), MNCH//2I0800994, WIVEE (V10), KAUZ/PASTOR (V11), DJEMILA (V15), WIFAK (V17), and Anapo (V19) are deemed unsuitable for bread-making purposes due to their lower protein content.

interpretations, only ANZA (V12) and HD (V18) may be categorized as high in wet gluten content. However, HIDHAB (V1), PASTOR (V5), DGA/BJY//FA*2 (V6), F94048GA-2/DELABRAD (V7), HXL7579/*2BAU (V8), YANGMAI1/GEN/WOOO30 (V9), KAUZ/PASTOR (V11), RMADA (V13), ANFORETA (V14), and Anapo (V19) did not meet the acceptable minimum.

Sedimentation value is one of the most essential ways for determining the amount and quality of protein, which is one

Table 3. Functional classification of Algerian wheat varieties

End-Use	Quality Requirements	Suitable Varieties
Bread	Protein > 11%, Wet gluten > 24%, Dry gluten > 8% Zeleny 40 ml–59 mL, P/L 0.61 to 1.20 W 201 to 400 (10–4 J), Ie: 45% to 50%,	*None met all criteria*
Biscuits/Cakes	Protein 7.9–9.7%, Moderate gluten, Zeleny 20.0–32.0 mL, L < 100 mm	Anapo, WIFAK
Chapati	Protein 11–12%, Dry gluten 8.5–11%, weaker gluten strength	AIN ABID, ARZ, PASTOR, DJEMILA, DJANATE, HD
Noodles	Wet gluten > 29.35%, Gluten index > 90, protein 10.68% to 13.94%, swelling index of glutenin (SIG) > 5.06	*None met criteria*
Blending	High tenacity + low tenacity	KAUZ/PASTOR (Extra-strong), Anza, HD, Djanat, MNCH//2*I0800994, WIVEE Inferior wheat)

In addition to protein content, wheat flour should have a minimum gluten level of 24% (wet) and 8% (dry). The higher the gluten level, the higher the quality of wheat flour for bread (Kaushik *et al.*, 2015). Our results showed that dry gluten content followed a similar pattern to protein levels, with ANZA (V12) and HD (V18) showing the highest values (10.30 ± 0.20% and 10.20 ± 0.26%, respectively), while Anapo (V19) exhibited the lowest value (5.50 ± 0.10%) ($\chi^2 = 54.55$, $p < 0.001$). Except for HIDHAB (V1), DGA/BJY//FA*2 (V6), F94048GA-2/DELABRAD (V7), HXL7579/*2BAU (V8), YANGMAI1/GEN/WOOO30 (V9), and Anapo (V19), all varieties achieved the minimum required levels of dry gluten.

The level of wet gluten is a major factor used in determining bread quality (Sirat, 2022). Values below 20% indicate soft wheat unsuitable for bread flour production. A range between 20% and 27% reflects low gluten strength, though often associated with higher protein content (Kurt & Yagdi, 2017). Wet gluten is generally considered high when it exceeds 27%, suggesting better suitability for bread-making applications (Sirat, 2022). According to these

of the most important quality parameters in wheat (Mut *et al.*, 2017; Sirat, 2022). In this study, YANGMAI1/GEN/WOOO30 (V9) achieved the highest value (36.67 ± 1.15 mL), followed by KAUZ/PASTOR (V11) (34.67 ± 0.58 mL), while the lowest values were recorded for RMADA (V13) (22.17 ± 0.29 mL) and Anapo (V19) (22.33 ± 0.58 mL) ($\chi^2 = 55.02$, $p < 0.001$). Notably, RMADA's (V13) high protein content did not correspond to high sedimentation values, suggesting differences in gluten quality composition. According to Kurt & Yagdi (2017), sedimentation values ranging from 20 to 39 mL indicate wheat with relatively low protein content, making them suitable for producing cookie flour, other specialty flours, or for blending with stronger wheat to produce standard wheat flour. In contrast, sedimentation values between 40 and 59 mL represent strong wheat, which is generally used in the production of bread flour. Based on these criteria, none of the 19 wheat varieties qualify as strong and, therefore, are not suitable for bread-making. The results indicate that all varieties fall within the 20–39 mL range, making them more suitable for cookie production or blending with stronger wheat rather than direct bread-making applications.

Since flours intended for biscuit and cake production are typically characterized by low to medium protein content (7.9% to 9.7%) and moderate gluten strength—reflected in intermediate Zeleny sedimentation values (20.0–32.0 mL)—as these attributes limit gluten development and promote a soft, tender crumb (Ma & Baik, 2018; Sumnu & Sahin, 2019), the WIFAK (V17) and Anapo (V19) varieties appear particularly suitable for such applications, due to their lower protein content and favorable gluten properties. Thanks to these characteristics, they are likely to produce high-quality biscuits with desirable height, shape factor, specific volume, and crumb softness.

Higher protein (11–12%) and gluten contents (8.5–11%) combined with weaker gluten strength are particularly desirable for chapati production, as they facilitate maximum dough sheeting without recoiling (Harisha *et al.*, 2025). In this regard, the profiles of varieties AIN ABID (V2), ARZ (V3), PASTOR (V5), DJEMILA (V15), DJANATE (V16), and HD (V18), based on their respective protein, gluten levels, and Zeleny values suggest their potential suitability for chapati-making applications.

For noodle production, flours are required to exhibit specific technological traits, including protein levels ranging from 10.68% to 13.94% (Iacovino *et al.*, 2025), a high wet gluten content (> 29.35%), a gluten index above 90.06, and a swelling index of glutenin (SIG) greater than 5.06. These properties promote the aggregation of gluten proteins into macropolymers, resulting in a compact and cohesive gluten network in cooked noodles (Wang *et al.*, 2025). However, none of the flours analyzed in the present study displayed a wet gluten content exceeding this critical threshold, indicating that the evaluated varieties are not suitable for noodle manufacturing.

The rheological parameters exhibited considerable variation among the studied varieties. The parameter P, which reflects dough resistance to deformation and strength properties during the initial phase of deformation (Jødal & Larsen, 2021) showed considerable variation. KAUZ/PASTOR (V11) exhibited the highest dough tenacity (103.33 ± 3.06 mm H_2O) and strength (277.00 ± 2.00 × 10^{-4} J), followed by RMADA (V13) for tenacity (100.00 ± 2.00 mm H_2O) and HXL7579/*2BAU (V8) for strength (273.00 ± 3.00 × 10^{-4} J).

Based on the classification from the literature, standard wheats are characterized by P values between 60- and 80-mm H_2O, which corresponds to our samples HIDHAB (V1), ARZ (V3), Ae-Squarrosa (Taus) Ben/4/Akla (V4), PASTOR (V5), DJEMILA (V15), ANFORETA (V14), and Anapo (V19). Very good grade wheats fall within the range of 80 to 100 mm H_2O, as observed in WIFAK (V17), RMADA (V13), YANGMAI1/GEN/WOOO30 (V9), HXL7579/2BAU (V8), F94048GA-2/DELABRAD (V7), DGA/BJY//FA2 (V6), and AIN ABID (V2). Extra-strong wheats, defined by P values exceeding 100 mm H_2O, are represented by KAUZ/PASTOR (V11) (Bordes *et al.*, 2008). However, HD (V18), DJANATE (V16), ANZA (V12), and MNCH//2*I0800994, WIVEE (V10) did not reach the minimum threshold required to be classified as standard wheat.

Strong wheat flours exhibit P/L ratios ranging from 0.61 to 1.20 and W values ranging from 201 to 400 (10–4 J) (Barros *et al.*, 2022). Only PASTOR (V5) can be described as strong wheat flour among the 19 varieties tested, with a P/L value of 0.98% and a W value of 218 (10–4 J). Strong wheat is commonly used in breadmaking (Kurt & Yagdi, 2017). Since PASTOR (V5) is considered as strong wheat, its flour may be used to make bread.

The elasticity index (Ie) value ranges from 25 to 75%, with 45 to 50% being ideal for bread-making flour and 50 to 55% being ideal for flour not destined for bread-making (Kitissou, 1995). ARZ (V3), DGA/BJY//FA*2 (V6), DJEMILA (V15), DJANATE (V16), WIFAK (V17), and HD (V18) exhibit Ie values ranging from 45% to 50%, indicating their suitability for breadmaking. Conversely, PASTOR (V5) and ANFORETA (V14), with Ie values between 50% and 55%, are more appropriate for other baked products.

Initially, we concluded that only variety PASTOR (V5) was suitable for bread production due to its high W and P/L values. However, the elasticity index results challenge this conclusion. Similarly, other varieties previously deemed unsuitable for bread production, based on their W and P/L values, were classified as acceptable for bread-making based on their Ie values. Therefore, we can conclude that relying on a single parameter is inadequate for accurately predicting dough behavior.

The discrepancy, between Figure 3A and Figure 3B, demonstrates the complexity of wheat quality relationships and explains why single-parameter assessment fails to predict end-use suitability. For instance, RMADA (V13) clusters differently when evaluated by composition versus rheological properties, highlighting that its high protein content (13.30%) does not translate to proportionally superior dough performance. This finding supports previous observations that protein quantity alone is insufficient for quality prediction (Kaushik *et al.*, 2015).

The clustering analysis endorses our earlier finding that no single variety met all bread-making criteria when assessed through integrated quality evaluation. The different clustering patterns between compositional and functional properties provide scientific evidence for the necessity of comprehensive quality assessment that includes both

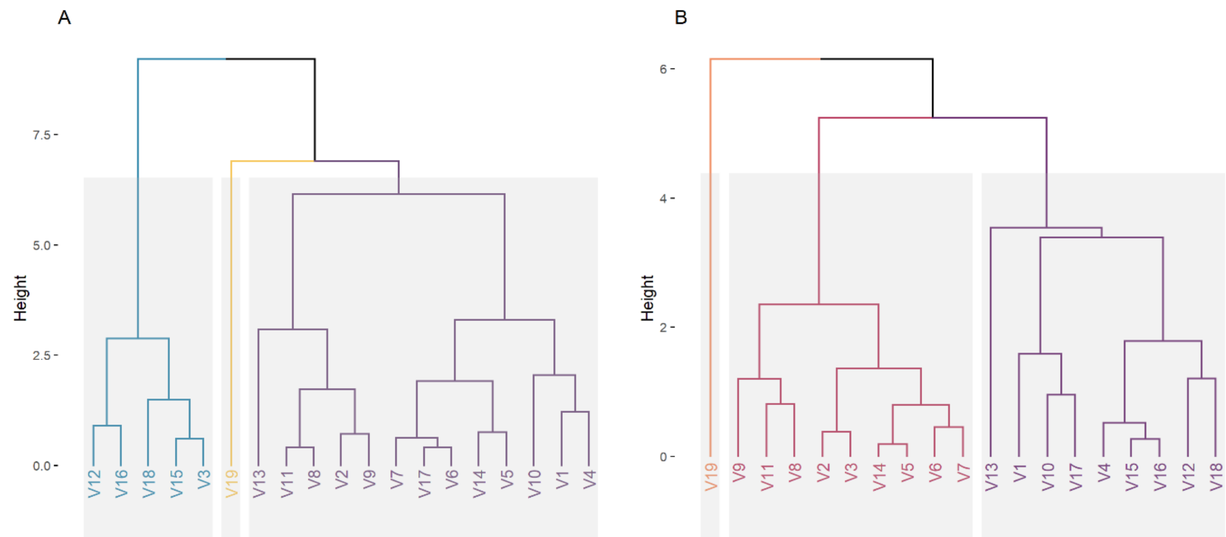

Figure 3. Hierarchical clustering of 19 wheat varieties based on two distinct trait domains. (A) Rheological parameters: W (10^{-4} J), P (mm H_2O), L (mm), G (cm^3), P/L ratio, and Ie (%). (B) Compositional quality traits: dry gluten (%), protein content (%), and Zeleny value (mL).

chemical composition and rheological testing, rather than relying solely on protein content or individual parameters.

This multivariate approach reveals that wheat quality assessment requires integration of multiple parameters, as the relationship between composition and functionality is not straightforward. The clustering patterns support the development of targeted breeding strategies and blending approaches, where varieties can be selected based on their specific quality profiles rather than attempting to develop single varieties that excel in all parameters simultaneously.

Study Limitations

A potential limitation of this study is that the wheat varieties were not cultivated under identical environmental conditions, as they were sourced from different locations. Additionally, the anonymous nature of some samples restricts access to deeper historical or genetic background information, which could have provided further insights into the observed technological properties. As a result, factors such as soil composition, climate, and agronomic practices may have contributed to the variation observed in flour quality traits. Nonetheless, the broad sampling across diverse agro-ecological zones enhances the applicability of our findings and provides a valuable baseline for selecting and improving Algerian wheat germplasm.

4 Conclusion

This study provides a characterization of nineteen Algerian bread wheat varieties, focusing on both compositional traits and rheological characteristics. Considerable variability was observed in protein content, gluten content and quality, as well as the alveographic parameters, reflecting the genetic diversity of the varieties. While none of the varieties fully met the stringent technological requirements for industrial bread or noodle production, several varieties exhibited promising dough strength and balanced tenacity/extensibility profiles, positioning them as potential candidates for future development. Other varieties, with lower rheological performance, may still hold potential for application in baked goods that require lower flour quality standards, such as biscuits, cakes, or traditional products.

Although the immediate industrial suitability of the studied flours remains limited, the results highlight promising potential that can serve as a foundation for improvement strategies. As future perspectives, several strategies could be explored to improve the technological suitability of these local flours. This includes blending with higher-quality flours to reach the required functionality for bread making, or enrichment with vital gluten to enhance baking performance. Moreover, application-oriented testing on traditional and sweet baked goods could help identify the most appropriate uses based on the intrinsic properties of these wheat varieties.

Ultimately, our findings offer a framework for leveraging local wheat resources in diverse end-use applications and for informing breeding programs aimed at enhancing national grain quality.

Acknowledgment: We acknowledge the authors of every study that was a part of this investigation.

Source of funding: None declared.

Previous submissions: The manuscript has not been presented in any scientific forum or meeting.

Authors' Contribution: **Messaoudene L.:** Conceptualization, methodology, data curation, formal analysis, investigation, methodology, writing - original draft, writing - review & editing. **Belguendouz A.**: Investigation, methodology, writing - original draft. **Medouni-Haroune L.**: Formal analysis. **Negrichi S.**: Writing - original draft. **Mellal M.K.**: Formal analysis, validation, visualization, Writing – review & editing.

Conflicts of Interest: No conflicts of interest are disclosed by the writers.

Preprint deposit: Authors did not share this manuscript as a preprint deposit.

REFERENCES

Abbes, A., (Rechreche, H., Medouri, A., Abbes, Z., & Benali, M. (2023). *Technological and biochemical analysis of the quality of five algerian soft wheat (triticum aestivum) varieties: use of the glutenins profiles as the allelic markers.* https://doi.org/10.5281/ZENODO.8018863 [Crossref] [Google Scholar] [Publisher]

Bellatreche, A., Mnasri, S. R., Ben Naceur, M., & Gaouar, S. S. B. (2019). Study of the molecular biodiversity of the Saharan bread wheat in Algeria. *Cereal Research Communications, 47*(4), 724–739. https://doi.org/10.1556/0806.47.2019.39 [Crossref] [Google Scholar] [Publisher]

Barros, J.H.T., Ribeiro, V.A. da G., Ferreira, M. de P.K., Steel, C.J., 2022. Bread-making performance of wheat flours enriched with vital gluten treated with non-thermal plasma. International Journal of Food Science & Technology, 57(6), 3795–3803. https://doi.org/10.1111/ijfs.15708 [Crossref] [Google Scholar] [Publisher]

Bessaoud, O. (2018). L'Algérie et le marché des céréales [ou] La question céréalière en Algérie et les marchés mondiaux. *In Géostratégie Alimentaire En Méditerranée: l'Enjeu Céréalier* (pp. 1–26). [Google Scholar]

Blandino, M., Marinaccio, F., & Reyneri, A. (2016). Effect of late-season nitrogen fertilization on grain yield and on flour rheological quality and stability in common wheat, under different production situations. *Italian Journal of Agronomy, 11*(2), 745. https://doi.org/10.4081/ija.2016.745 [Crossref] [Google Scholar] [Publisher]

Bordes, J., Branlard, G., Oury, F. X., Charmet, G., & Balfourier, F. (2008). Agronomic characteristics, grain quality and flour rheology of 372 bread wheats in a worldwide core collection. *Journal of Cereal Science*, *48*(3), 569–579. https://doi.org/10.1016/j.jcs.2008.05.005 [Crossref] [Google Scholar] [Publisher]

Calvi, A., Preiti, G., Gastl, M., Poiana, M., & Zarnkow, M. (2023). Malting process optimization of an Italian common wheat landrace (Triticum aestivum L.) through response surface methodology and desirability approach. *Lebensmittel-Wissenschaft Und Technologie [Food Science and Technology]*, *173*(114242), 114242. https://doi.org/10.1016/j.lwt.2022.114242 [Crossref] [Google Scholar] [Publisher]

Chakrabarti-Bell, S., Lukasczyk, J., Liu, J., Maciejewski, R., Xiao, X., Mayo, S., & Regenauer-Lieb, K. (2021). Flour Quality effects on percolation of gas bubbles in wheat flour doughs. *Innovative Food Science & Emerging Technologies: IFSET: The Official Scientific Journal of the European Federation of Food Science and Technology*, *74*(102841), 102841. https://doi.org/10.1016/j.ifset.2021.102841 [Crossref] [Google Scholar] [Publisher]

Chapla, P. I., Vieira, E. S. N., Franco, F. A., Linde, G. A., Silva, G. J., Colauto, N. B., Marchioro, V. S., & Schuster, I. (2017). High molecular weight glutenin subunits and the classification used in Brazilian wheat industry. *Genetics and Molecular Research: GMR*, *16*(3). https://doi.org/10.4238/gmr16039744 [Crossref] [PubMed] [Google Scholar]

Dinno, A. (2023). Package 'dunn. test'. CRAN Repos, 10, 1-7 [Crossref]

FAO (2022). GIEWS Country Brief on Algeria https://www.fao.org/giews/countrybrief/country.jsp?code=DZA&lang=fr

Indrani, D., Manohar, R. S., Rajiv, J., & Rao, G. V. (2007). Alveograph as a tool to assess the quality characteristics of wheat flour for parotta making. *Journal of Food Engineering*, *78*(4), 1202–1206. https://doi.org/10.1016/j.jfoodeng.2005.12.032 [Crossref] [Google Scholar] [Publisher]

Jødal, A.-S. S., & Larsen, K. L. (2021). Investigation of the relationships between the alveograph parameters. *Scientific Reports*, *11*(1), 5349. https://doi.org/10.1038/s41598-021-84959-3 [Crossref] [PubMed] [Google Scholar] [Publisher]

Harisha, R., Ahlawat, A. K., Balakrishnan, A. P., Bhavya, B., Singhal, S., Manjunath, K. K., Harshitha, B. S., Shekharappa, N., Sonu, & Singh, V. J. (2025). Exploring the intricate interplay between the physico-chemical and biochemical properties of grain, refined wheat flour, and whole wheat flour in determining chapati (Indian flatbread) quality of wheat (Triticum aestivum L.). *Applied Food Research*, *5*(1), 100956. https://doi.org/10.1016/j.afres.2025.100956 [Crossref] [Google Scholar] [Publisher]

Hernández-Espinosa, N., Mondal, S., Autrique, E., Gonzalez-Santoyo, H., Crossa, J., Huerta-Espino, J., Singh, R. P., & Guzmán, C. (2018). Milling, processing and end-use quality traits of CIMMYT spring bread wheat germplasm under drought and heat stress. *Field Crops Research*, *215*, 104–112. https://doi.org/10.1016/j.fcr.2017.10.003 [Crossref] [Google Scholar] [Publisher]

Hu J., Zhang J., Wang W.,Liu J.,Tang H., Wan Y., Zhang X., Huang W., Li X., Yan Y., Ye Y., & Wang K. (2025). Effects of a dramatic composition change of high-molecular-weight glutenin subunits by gene editing on flour-processing quality in wheat. Journal of Integrative Agriculture. X(X), X–X. https://doi.org/10.1016/j.jia.2025.05.017 [Crossref] [Google Scholar] [Publisher]

Iacovino, S., Garzon, R., Rosell, C. M., Marconi, E., Albors, A., & Martín-Esparza, M. E. (2025). Evaluation of the technological performance of soft wheat flours for fresh-pasta production as affected by industrial refining degree. *Food and Bioprocess Technology*, *18*(3), 2854–2866. https://doi.org/10.1007/s11947-024-03638-z [Crossref] [Google Scholar] [Publisher]

Karaduman, Y., Sayaslan, A., & Akın, A. (2020). GlutoPeak parameters of whole wheat flours for gluten quality evaluation in soft wheat breeding programs. *Journal of Cereal Science*, *95*(103031), 103031. https://doi.org/10.1016/j.jcs.2020.103031 [Crossref] [Google Scholar] [Publisher]

Kassambara, A., & Mundt, F. (2017). Package 'factoextra'. Extract and visualize the results of multivariate data analyses 76. https://doi.org/10.32614/cran.package.factoextra [Crossref] [Publisher]

Kaushik, R., Kumar, N., Sihag, M. K., & Ray, A. (2015). Isolation, characterization of wheat gluten and its regeneration properties. *Journal of Food Science and Technology*, *52*(9), 5930–5937. https://doi.org/10.1007/s13197-014-1690-2 [Crossref] [PubMed] [Google Scholar] [Publisher]

Kelly, J. M., Bohman, B., Bennett, D., & Taylor, N. L. (2025). Rapid dough making quality analysis of wheat flour using Fourier transform infrared spectroscopy and chemometrics. *Food Chemistry, 475*(143335), 143335. https://doi.org/10.1016/j.foodchem.2025.143335 [Crossref] [PubMed] [Google Scholar] [Publisher]

Khomych, G., Horobes, A., Levchenko, Y., Vysotska, S., & Korniienko, L. (2020). The flour of soft wheat in the technologies of food products. Scientific Messenger of LNU of *Veterinary Medicine and Biotechnologies, 22*(93), 3–8. https://doi.org/10.32718/nvlvet-f9301 [Crossref][Google Scholar] [Publisher]

Kurt Polat, P.O., Yagdi, K., 2017. Investigation of relationship between some quality characters of winter wheat genotypes. *Turkish Journal of Field Crops.* https://doi.org/10.17557/tjfc.311016 [Crossref][Google Scholar] [Publisher]

Ma, F., & Baik, B.-K. (2018). Soft wheat quality characteristics required for making baking powder biscuits. *Journal of Cereal Science, 79,* 127–133. https://doi.org/10.1016/j.jcs.2017.10.016 [Crossref] [Google Scholar] [Publisher]

Meenu, M., Kaur, S., Yadav, M., Sharma, A., Tiwari, V., Ali, U., Giri, L., Badwal, A. K., & Garg, M. (2024). Impact of inherent chemical composition of wheat and various processing technologies on whole wheat flour and its final products. *Cereal Research Communications*. https://doi.org/10.1007/s42976-024-00544-0 [Crossref] [Google Scholar] [Publisher]

Mut, Z., Erbaş Köse, Ö. D., & Akay, H. (2017). Determination of grain yield and quality traits of some bread wheat (*Triticum aestivum* L.) varieties. *Anadolu Journal of Agricultural Sciences*, 32(1), 85–85. https://doi.org/10.7161/omuanajas.288862 [Crossref] [Publisher]

Oikonomou, N.A., Bakalis, S., Rahman, M.S., Krokida, M.K., 2015. Gluten Index for Wheat Products: Main Variables in Affecting the Value and Nonlinear Regression Model. Int. J. *International Journal of Food Properties*, *18*(1), 1–11. https://doi.org/10.1080/10942912.2013.772198 [Crossref] [Google Scholar] [Publisher]

Oksanen, J., Kindt, R., Legendre, P., O'Hara, B., Stevens, M. H. H., Oksanen, M. J., & Suggests, M. A. S. S. (2007). *The vegan package. Community ecology package, 10*(631-637), 719. [Publisher]

Ouzani, Y., Hiouani, F., Ahmad, M. J., & Choi, K.-S. (2025). Impact of climate change on wheat production in Algeria and optimization of irrigation scheduling for drought periods. *Water, 17*(11), 1658. https://doi.org/10.3390/w17111658 [Crossref] [Google Scholar] [Publisher]

R: A language and Environment for Statistical Computing. (2024). In *R Foundation for Statistical Computing*.

Rababah, T., Aludatt, M., Al-Mahasneh, M., Gammoh, S., Al-Obaidy, M., Ajouly, T., & Bartkute-Norkūniene, V. (2019). The effect of different flour extraction rates on physiochemical and rheological characteristics. *Bulgarian Journal of Agricultural Science*, *25*(3), 581–588. https://doi.org/10.1080/19476337.2019.1693430 [Crossref][Google Scholar] [Publisher]

Sakr, N., Rhazi, L., & Aussenac, T. (2021). Bread wheat quality under limiting environmental conditions: II – Rheological properties of Lebanese wheat genotypes. *Journal of the Saudi Society of Agricultural Sciences, 20*(4), 235–242. https://doi.org/10.1016/j.jssas.2021.02.002 [Crossref][Google Scholar] [Publisher]

Sirat, A., 2022. Investigation of Yield and Quality Parameters of Some Local and Newly Registered Bread (hexaploid) Wheat (Triticum aestivum L.) Genotypes Under Rainfed Agricultural Conditions. *Gesunde Pflanzen 74*, 1071–1085. https://doi.org/10.1007/s10343-022-00694-3 [Crossref][Google Scholar] [Publisher]

Sumnu, S. G., & Sahin, S. (Eds.). (2019). *Food engineering aspects of baking sweet goods*. CRC Press. [Crossref] [Publisher]

Tozatti, P., Güldiken, B., Fleitas, M. C., Chibbar, R. N., Hucl, P., & Nickerson, M. T. (2020). The interrelationships between wheat quality, composition, and dough rheology for a range of Western Canadian wheat cultivars. *Cereal Chemistry*, *97*(5), 1010–1025. https://doi.org/10.1002/cche.10324 [Crossref][Google Scholar] [Publisher]

Wang, J., Liu, C., Wang, Z., Che, R., Hong, J., Liu, M., Sun, B., Shang, J., Liu, Z., Guan, E., & Zheng, X. (2025). Relation between quality characteristics of wheat flour and in vitro starch digestibility of dried noodles: Insights from noodle structure. *International Journal of Biological Macromolecules*, *313*(144337), 144337. https://doi.org/10.1016/j.ijbiomac.2025.144337 [Crossref] [PubMed] [Google Scholar] [Publisher]

Živančev, D., Mirosavljević, M., Aćin, V., Momčilović, V., Mikić, S., Torbica, A., & Jocković, B. (2022). Variation in quality traits of newly developed Serbian wheat cultivars under different environmental conditions of Pannonian plain. *Italian Journal of Agronomy*, *17*(1), 1911. https://doi.org/10.4081/ija.2021.1911 [Crossref] [Google Scholar] [Publisher]