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Research Article

EFFECT OF DIFFERENT MILLING METHODS ON THE QUALITY CHARACTERISTICS OF HIGHLY EXTRACTED WHEAT FLOUR AND BREAD

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ABSTRACT

This study addresses the challenge of conventional wheat milling, which often reduces the nutritional value of flour by removing bran and germ. The importance of this work is to produce highly extracted wheat flour (≥92%) retaining more nutrients and improves resource efficiency. This study aimed to evaluate the impact of different milling methods (stone, electric-grinder, and roller milling) on the quality characteristics of the extracted wheat flour produced from three Egyptian wheat varieties. Physical, chemical, rheological, and phytochemical properties of the produced flours and their corresponding bread were determined. Stone milling recorded the highest flour extraction rates (up to 94.45%) and produced finer particles with higher protein, crude fiber, ash, and fat content compared to roller milling, which produced lighter-colored and more refined flour with lower nutrient content. Stone-milled flour also showed superior water holding capacity, gluten quality, and dough rheological properties, resulting in bread with higher weight, improved moisture retention, and reduced staling rate during storage. Roller-milled flour, however, produced lighter-colored bread with comparable sensory acceptability. Overall, the results demonstrate that milling method non significantly influences flour quality, functionality, and bread characteristics. Stone milling, provided flours of higher nutritional and functional value suitable for whole-grain and functional bakery products.

1. Introduction

Cereal based products, mainly bread, play a significant role in human nutrition due to their high nutritional value as well as they are a source of energy and nutrients (Dziki et al. 2014). Wheat (*Triticum aestivum* L.) is a crucial cereal crop worldwide. It has high nutritional value due to its health promoting components such as protein, fiber, and phytochemicals (Shewry and Hey, 2015). The whole wheat grains contain three milling fractions which are the endosperm, germ, and bran. The endosperm (the major component) is mainly starch, and represents 81-84% of the grain. Wheat germ accounts for 2-3% of the grain and contains mostly fat and protein. The wheat bran, which is mainly composed of dietary fiber, is the outermost part of the grain

(14-16%) contains the aleurone layer, which is a part of the endosperm that is removed during roller milling along with the bran (McMackin et al. 2013). Furthermore, the germ and bran are rich in dietary fiber, fructans, and other bioactive substances like phenolic compounds, which have been correlated with a lower risk of some diseases (Ragaee et al. 2011). Regarding wheat flour, it is composed of starch and gluten which have a significant impact on the structural characteristics and functional properties of the flour (Goesaert et al. 2005). Research on cereal starches indicated that intensive grinding could decrease the enthalpy and temperature of starch gelation and the soluble matter content because of a minor depolymerization of both amylose and amylopectin (Liu et al. 2011). Quality of wheat flour products can be evaluated by analyzing the functional properties of flour, which can be optimized by adjusting milling conditions (Cappelli et al. 2020a; Cappelli and Cini, 2021). The quality and suitability of end products are significantly affected by the milling process (Yu et al. 2018). During wheat milling, most of the bran and germ parts are removed, resulting in the loss of numerous important antioxidants, vitamins, minerals, and dietary fibers. Whole grains flour is produced by recombining bran and germ with endosperm flour in the naturally occurring proportions (Liu et al. 2015).

The most common physical forces applied in the milling process to reduce particles size are shearing, compression, impact, and friction (Posner and Hibbs, 2005). The mechanical force is mainly selected to increase the flour yield, as a measure of commercial value. During the milling process, the endosperm is maintained to the greatest possible extent to maximize the flour yield, while the bran layer is removed as much as possible using shear force (Hourston et al. 2017; Doblado-Maldonado et al. 2012; Mousia et al. 2004). After the endosperm is scraped from the bran, further milling mainly affects the quality of flour using different milling processes or various experimental mills (Yu et al. 2015; Wang et al. 2017; Niu et al. 2014; Gomez et al. 2009). Roller and stone mills are the most widely used milling techniques (Doblado-Maldonado et al. 2012). Numerous studies have revealed that the milling method for cereal grains (such as wheat, barley, and rye) influences the color, particle size, surface area, damaged starch, and functional properties of the flour, resulting in flours with different physicochemical properties (Pang et al. 2020; Yu et al. 2018; Liu et al. 2018; Albergamo et al. 2018; Ficco et al. 2016). Roller mill is widely used in the food industry (Cappelli et al. 2020b). However, stone mill is preferable by some bakers and food producers, compared with roller mill, due to its favorable influence on the texture and flavor of the final products. During grinding, the bran, germ, and endosperm are broken down, therefore different grinding processes could produce flour with different particle size distributions and chemical composition. When a mechanical force is applied to solid materials, it causes both physical changes such as breaking, splitting, and deformation, as well as changes in their internal structure and physicochemical qualities (Saranu et al. 2011).

The present study aimed to investigate the influence of different milling methods (stone, electric-grinder, and roller) on the physical, chemical, functional, and phytochemical characteristics of highly extracted wheat flour (≥92%) produced from three Egyptian bread wheat varieties (Gemmiza-11, Giza-171, and Sakha-95). Also to assess the influence of different milling methods on the dough rheological behavior and the final quality characteristics of traditional Balady bread.

2. Materials and methods

2.1. Materials

Egyptian bread wheat varieties (Gemmeiza 11, Sakha-95 and Giza171) were obtained from the Field Crops Research Institute, Agricultural research center, Egypt.

All chemicals and reagents used were of analytical reagent grade.

2.2. Methods

2.2.1. Physical properties

The wheat grains were analyzed for physical characteristics. Hectoliter weight (test weight) of the wheat grains was measured using the Schoper System on a Dalle Molle balance (Caxias RS, Brazil) as described by the AACC (2002) method. Thousand grains of wheat were counted and weighed to determine the thousand grains weight in grams. The color of whole wheat grains, wheat flour (≈ 92- 95% extraction rate), and balady bread loaves (crust and crumb) were measured with a porTable Chromameter (model CR-400, Konica Minolta, Japan). The obtained values were described as L^* for the lightness-darkness, a^* for the redness-greenness, and b^* for the yellowness-blueness.

2.2.2. Milling (Wheat flour preparation)

Wheat varieties were tempered to a final moisture content of 14%, divided into three portions to mill with various milling techniques using different millers (stone, electric-grinder, and roller), and then sieved. Stone-milled flour was obtained using stone mills being the oldest attrition mills used to obtain whole grain flours. Stone-mills apply compression, shear, and abrasion at the same to grind wheat grains between two stones producing a theoretical extraction rate to obtain (≈ 92- 95 % extraction rate) (Kihlberg et al. 2004). A high-speed (28000 RPM) laboratory grinder (MDY-2000, China) was used to produce electric-grind flour. Roller-milled flour was obtained using a laboratory flour fraction mill (Brabender Duis-burg Roller Mill, Germany). The obtained bran and shorts were reground by reducing the gap between the rolls. Extraction rate is the maximum flour quantity of a specific quality from the wheat grains and is calculated as follows (Equation 1).

$$\text{Extraction rate (\%)} = \frac{\text{flour weight (g)}}{\text{initial wheat weight (g)}} \text{ x } 100 \qquad (1)$$

2.2.3. Flour fractionation based on particles size

The particle size of the extracted flour samples obtained using different millers was measured by sieving 200 g of flour sample using a Lab Sifter (FRITSCH, Germany) for 10 min. The sieves opening of 160, 200, 355 and 400 µm diameters were used. The flour remained on each sieve was weighed and expressed as g/100 g.

2.2.4. Chemical composition

Moisture, protein, ash, crude fiber, and fat contents of wheat whole meal, flour, and balady bread were determined according to the methods of the Association of Official Agricultural Chemists (AOAC 2019). Total carbohydrates content (TC, %) was calculated by the difference (Equation 1).

$$\text{TC (\%)} = 100 - (\text{protein} + \text{fat} + \text{ash} + \text{crude fiber}) \qquad (2)$$

2.2.5. Functional properties

The water holding capacity (WHC) and oil holding capacity (OHC) of the wheat flour were measured using the technique outlined by Traynham et al. (2007). One gram of flour was combined with either ten milliliters of distilled water (WHC) or sunflower oil (OHC) in pre-weighed centrifuge tubes. Following the addition of the flour and the respective liquids, the mixture was thoroughly mixed, kept for 30 min and then subjected to centrifugation (at a speed of 4000 rpm for 20 minutes). The amount of water or oil absorbed by the flour was determined as a percent of weight gained.

2.2.6. Gluten content

Wet and dry gluten content (%) were determined in accordance with the methods of the Association of Official Agricultural Chemists (AOAC 2019).

2.2.7. Phytochemicals content

Total phenolic content (TPC) of flour samples was determined, according to Singleton and Rossi (1965), using the Folin-Ciocalteu reagent method. According to Fischer et al. (2013), the 2.2-diphenyl-2-picryl-hydrazyl (DPPH) method was used to determine the antioxidant activity, which is

defined as free radical scavenging activity (%). The following formula was used to measure the scavenging activity.

$$\text{DPPH radical scavenging activity (\%)} = \frac{A_o - A_1}{A_o} \times 100 \quad (3)$$

Where A_o and A_1 are the absorbance of the control sample and the flour extracts, respectively after 30 mins.

2.2.8. Rheological properties of dough

Rheological properties of dough from different flour samples were determined using farinograph and extensograph characteristics according to the methods of AACC (2002). The parameters obtained from a Brabender farinograph were water absorption (water utilized to produce dough with a consistency of 500 BU), dough development time (DDT, time for maximum consistency), dough stability time (DST, time during dough consistency is at 500 BU), and mixing tolerance index (consistency difference between height at peak and to that five minutes later). Brabender extensograph gives the measurement of the viscoelastic behavior of dough by measuring the dough extensibility, and resistance to uniaxial extension.

2.2.9. Bread preparation and characterization

2.2.9.1. Balady bread preparation

Balady bread was produced using the formula of 100 g of the obtained flour samples obtained by different milling methods, instant dry yeast (1 g), and Table salt (1 g). All ingredients were mixed using the straight dough method, along with the amount of water estimated from farinograph test. Dough samples were kept to ferment in a fermentation cabinet at 35±2 °C for 50 minutes and a relative humidity (80 %). Dough is portioned into 120–130 g pieces on a layer of fine wheat bran and allowed to ferment again for 30 minutes. Then the dough pieces were flattened and allowed to ferment for 15 min, and finally baked at 450–500 °C. The baked balady bread loaves were allowed to cool before additional examination.

2.2.9.2. Sensory evaluation

The bread loaves were evaluated for sensory acceptability after cooling to room temperature based on the nine points hedonic scale (9= extremely like, 5= neither like nor dislike, and 1= extremely dislike) by 15 panelists from Food Technology Research Institute, Agricultural Research Center, Egypt. Appearance, layers separation, color of the crust and crumb, odor, crumb distribution, chewing ability, taste, and overall acceptability were estimated using Stone and Sidel method (1993). The sensory evaluation protocol followed the Declaration of Helsinki's ethical criteria, and ethical approval was received from the Sensory Evaluation Ethics Committee (Approval No. SEC-22), as well as signed agreement from all participants.

2.2.9.3. Moisture loss and staling rate

Moisture content of balady bread samples was measured after storage at room temperature (25°C) for 0, 24, 48, and 72 hours. Balady bread samples were oven dried after different storage periods at room temperature to determine Alkaline Water Retention Capacity (AWRC, %). The staling rate (%) of balady bread was calculated during storage periods using the Alkaline Water Retention Capacity method, as described by Yamazaki (1953) and modified by Kitterman and Rubenthaler (1971), using the following equation:

$$\text{Staling rate (\%)} = \frac{AWRC_o - AWRC_n}{AWRC_o} \, x \, 100 \quad (4)$$

Where $AWRC_o$ is the AWRC at zero time and $AWRC_n$ is the alkaline water retention capacity after 24, 48 and 72 hours.

2.2.10. Statistical analysis

The Costat statistical program was utilized to statistically evaluate the obtained data in order to determine the means and standard deviations (Steel et al. 1997). To evaluate

differences between sample means, the data were first subjected to a one-way analysis of variance (ANOVA), and then Duncan's multiple range tests (at $p \leq 0.05$).

3. Results and discussion

3.1. Physical and chemical properties of whole meal

Before extraction of wheat flour, quality characteristics of whole meal (Gemmiza-11, Giza-171, and Sakha-95 varieties) were analyzed and presented in Table 1. Thousand grains weight (g) and hectoliter weight (kg/hl) reflect the grains size and density. Hectoliter weight is a key physical quality indicator to the flour yield and is influenced by grains size and shape. The average thousand grains and hectoliter weight ranged from 56.89 to 59.58g and 77.47 to 80.72 kg/hl in Sakha-95 and Gemmiza-11, respectively. Regarding color attributes, L^* (lightness), a^* (redness-greenness), and b^* (yellowness-blueness) values are shown Table 1.

Table 1. Physical and chemical properties of different bread wheat varieties

Parameter	Gemmiza-11	Giza-171	Sakha-95
1000 grains wt (g)	59.58±1.41^{a}	58.97±1.07^{ab}	56.89±0.53^{b}
Hectoliter (kg/hl)	80.72±0.26^{a}	79.61±0.10^{b}	77.47±0.19^{c}
L^*	73.08±2.33^{a}	71.05±3.19^{ab}	66.63±0.78^{b}
a^*	4.37±0.42^{b}	5.61±0.35^{a}	5.27±0.37^{a}
b^*	20.06±0.85^{a}	21.17±0.80^{a}	21.29±1.02^{a}
Chemical composition (%)			
Moisture	11.16±0.10^{b}	10.71±0.07^{c}	11.77±0.05^{a}
Protein	11.66±0.05^{c}	12.00±0.02^{b}	12.15±0.04^{a}
Fat	1.76±0.13^{b}	2.03±0.14^{a}	1.94±0.13^{a}
Ash	1.59±0.01^{c}	1.83±0.01^{a}	1.78±0.01^{b}
Fiber	2.35±0.06^{b}	2.57±0.03^{a}	2.56±0.06^{a}
Total carbohydrates	82.64±0.03^{a}	81.57±0.13^{b}	81.57±0.12^{b}

Values are means of three replicates ± SD. Values in the same row followed by different superscripts are significantly different ($p \leq 0.05$). Protein, ash, fat, crude fiber, and total carbohydrates were calculated on a dry weight basis.

Color of wheat grains is an important property in grain sorting and marketing of wheat grains, as it is critical in the milling and baking industries as it affects the color of wheat products (Wu et al. 1999; Jiang et al. 2011). Several studies reported that the wheat grain color influences the appearance and color of the final wheat products, such as bread and tortillas (Li and Posner, 1989; Seib, et al. 2000). Gemmiza-11 variety has the highest L^* value (73.08) while Sakha-95 has the lowest one (66.63). Among the studied wheat varieties, the mean values of a^* and b^* values ranged from 4.37 to 5.61 and 20.06 to 21.29, respectively. Moisture, protein, fat, ash, and crude fiber contents of wheat grains was in the range of 10.71-11.77%, 11.66-12.15%, 1.76-2.03%, 1.59-1.83%, and 2.35-2.57%, respectively.

3.2. Flour extraction rate (%)

The extraction rate (%) of the three wheat varieties using the different milling methods are presented in Table 2 and it was in the range of 89.67-94.45%. It was the highest in stone-milled flour followed by flour milled with electric-grinder across all wheat varieties. Roller-milled flour showed the lowest flour yield as the roller milling process includes separation of the bran and germ from the endosperm fraction followed by gradual size reduction of endosperm (Liu, 2015). The milling method significantly influences the quality of wheat flour, the rheological properties of dough, and bread characteristics.

Numerous authors have underlined the necessity of selecting the most appropriate process, given the desired impacts on wheat flour, dough, and bread (Albergamo et al. 2018; Ficco et al. 2016; Liu et al. 2018; Yu et al. 2018).

Table 2. Effect of milling methods on extraction rate (%) and particles size distribution (%) of different flour samples

Milling Methods	Extraction rate (%)	Particles size distribution (%)				
		≥399 µm	399-355 µm	354-200 µm	199-160 µm	≤160 µm
Gemmiza-11						
Stone	94.45±0.23^{a}	20.90±0.09^{b}	0.59±0.02^{c}	6.78±0.15^{c}	1.69±0.06^{a}	70.04±0.28^{a}
Electric-grinder	93.90±0.21^{a}	24.87±0.04^{a}	3.33±0.06^{a}	19.77±0.18^{b}	1.66±0.04^{a}	50.37±0.32^{c}
Roller	90.41±0.53^{b}	10.20±0.14^{c}	0.97±0.02^{b}	25.99±0.16^{a}	1.55±0.05^{a}	61.29±0.36^{b}
Giza-171						
Stone	94.07±0.67^{a}	23.10±0.09^{b}	1.19±0.05^{c}	8.09±0.06^{c}	3.27±0.06^{b}	64.35±0.14^{a}
Electric-grinder	93.80±0.23^{a}	25.93±0.11^{a}	4.03±0.05^{a}	21.56±0.08^{b}	2.39±0.04^{c}	46.09±0.28^{c}
Roller	89.79±0.23^{b}	14.44±0.08^{c}	1.83±0.04^{b}	24.05±0.15^{a}	3.81±0.04^{a}	55.88±0.31^{b}
Sakha-95						
Stone	93.27±0.75^{a}	22.97±0.16^{b}	1.12±0.03^{c}	8.06±0.10^{c}	3.29±0.06^{a}	64.57±0.16^{a}
Electric-grinder	92.96±0.24^{a}	25.96±0.07^{a}	4.95±0.08^{a}	21.53±0.15^{b}	1.86±0.04^{c}	45.71±0.18^{c}
Roller	89.67±0.38^{b}	15.11±0.02^{c}	2.17±0.06^{b}	29.94±0.21^{a}	2.64±0.06^{b}	50.14±0.31^{b}

Values are represented as means of three replicates ± SD. Values in the same column for each wheat variety separately, followed by different superscripts are significantly different ($p \leq 0.05$).

3.3. Flour fractionation based on particles size

The evaluation of particle size distribution is significant in demonstrating the rheological properties of dough, as the particle size of bran and flour can influence water absorption and gluten aggregation kinetics. The effect of different milling methods (stone, electric-grinder, and roller) on the particles size distribution of flour samples obtained from three wheat varieties (Gemmiza-11, Giza-171, and Sakha-95) is shown in Table 2. The results showed clear differences in the proportion of coarse and fine fractions depending on both the milling technique and the wheat varieties. For Gemmiza-11, stone milling produced the highest proportion of fine particles (≤160 µm; 70.04%) compared to electric-grinder (50.37%) and roller milling (61.29%). Conversely, the electric-grinder mill yielded a higher proportion of coarse fractions (≥399 µm) due to the impact-based mechanism that tends to shatter grains irregularly, producing a wide range of particles size. Roller milling gave a moderate proportion of fine fraction compared to other milling methods, consistent with its controlled shearing and compression mechanism (Posner and Hibbs, 2005). A similar trend was observed in Giza-171 and Sakha-95, the electric-grinder milling generated the highest amount of coarse particles and the lowest proportion of fine ones. Overall, stone milling consistently produced the finest flour fractions across all wheat varieties. Differences among wheat varieties likely arise from variations in grain hardness, protein, and moisture contents, which influence the mechanical breakdown of the grain during milling. Fine particle size is desirable for improved dough rheology and bread-making quality. In contrast, coarser particles may enhance fiber content and nutritional value in whole-grain applications (Prabhasankar and Rao, 2001; Dziki et al. 2014). Regarding the effects of milling methods on wheat flour characteristics, it was reported that stone milling yielded a more uniform particle size flour and narrower particle size distribution, compared to roller

milling (Liu et al. 2018). Whereas, according to Kihlberg et al. (2004), stone-milled flour had a larger distribution of particle sizes in the central range (>400 to ≤800 μm) compared to roller-milled flour.

3.4. Color and functional properties of wheat flour

The color attributes (L^*, a^*, and b^*) of flour obtained by different milling methods are presented in Table 3. Significant variations ($p \leq 0.05$) were observed among the milling techniques and wheat varieties, reflecting the influence of milling conditions and wheat variety on flour color attributes. Among all wheat flours, L^* values (lightness) varied significantly across milling methods and ranged from 90.95 to 98.11. This result is in agreement with previous findings indicating that the milling method and particle size have a considerable effect on lightness (He et al. 2018; Hu et al. 2012). It was concluded that as particle size reduced, the surface area increased, and the internal structure of cellulose and hemicellulose becomes more exposed, which influences the color of the flour (Zhao et al. 2010). With respect to wheat flour samples, roller-milled flour consistently had the highest L^* values indicating a lighter color compared to other milling methods. This could be due to the lower extraction rare and ash content of the roller-milled flour. It was reported that, the color of the flour is affected by both the extraction rate and ash content, and as the extraction rate decreased, the ash content also decreased and the color became lighter (Kihlberga et al. 2004). On the other hand, flours milled using electric-grinder had significantly ($p \leq 0.05$) the lowest L^* values while the highest a^* (redness) and b^* (yellowness) values which could be due to the browning effect of heat generated during this milling method. This difference can be attributed to the different bran contamination, presence of carotenoid pigments, and various particle sizes in the produced flour samples with different pigment content (Sakhare et al. 2013).

Table 3. Color and functional characteristics of wheat flours extracted by various milling methods from different wheat varieties

Milling methods	Color attributes			Functional characteristics (%)	
	*L**	*a**	*b**	WHC	OHC
Gemmiza-11					
Stone	96.44±0.36^{b}	0.31±0.02^{b}	8.75±0.10^{b}	94.82±0.61^{a}	85.63±0.01^{b}
Electric-grinder	94.98±0.32^{c}	0.46±0.05^{a}	9.58±0.44^{a}	68.82±0.26^{b}	64.81±0.14^{c}
Roller	98.11±0.53^{a}	0.26±0.02^{b}	7.38±0.29^{c}	65.91±0.70^{c}	94.34±0.36^{a}
Giza-171					
Stone	95.87±0.08^{b}	0.45±0.05^{b}	9.39±0.12^{b}	92.59±0.80^{a}	89.01±0.05^{b}
Electric-grinder	93.20±0.15^{c}	0.72±0.03^{a}	10.85±0.15^{a}	72.29±0.30^{b}	64.24±0.16^{c}
Roller	96.75±0.13^{a}	0.38±0.04^{c}	9.24±0.35^{b}	69.53±0.71^{c}	97.48±0.32^{a}
Sakha-95					
Stone	93.13±0.10^{b}	0.36±0.02^{b}	9.29±0.09^{b}	90.22±0.72^{a}	85.26±0.10^{b}
Electric-grinder	90.95±0.08^{c}	0.58±0.04^{a}	10.79±0.04^{a}	81.94±0.85^{b}	67.37±0.05^{c}
Roller	94.91±0.11^{a}	0.32±0.02^{b}	9.05±0.28^{c}	73.16±0.63^{c}	92.47±0.22^{a}

Data are presented as means ± SD. For each wheat variety separately, values within each column with different superscripts are significantly different ($p \leq 0.05$).

Water and oil holding capacities (WHC and OHC) of wheat flour extracted by various milling methods from different wheat varieties are presented in Table 3. The results revealed that the WHC of the flour samples varied significantly ($p \leq 0.05$) among milling methods and wheat varieties. Stone-milled flour recorded the highest WHC across all varieties (94.82, 92.59, and 90.22% for Gemmiza-11, Giza-171, and Sakha-95, respectively). Meanwhile, roller-milled flour showed the lowest values (65.91, 69.53, and 73.16% for Gemmiza-11, Giza-171, and Sakha-95, respectively). The higher WHC in stone-

milled flour could be attributed to the higher extraction rate within more bran fraction, and higher protein and fiber contents. The lowest WHC in roller-milled flour may result from the removal of outer bran layers during milling (Kihlberg et al. 2004; Dziki et al. 2014). Moreover, the difference in WHC could be attributed to particles composition, shape, and the disruption extent of bran matrix structure (Cadden, 1987). Regarding OHC, it ranged from 64.24 to 97.48% and roller-milled flour had significantly the highest values across all wheat flours followed by stone-milled flour.

3.5. Chemical composition and gluten content of flour

The chemical composition of flour extracted from three wheat varieties (Gemmiza-11, Giza-171, and Sakha-95) using different milling methods (stone, electric-grinder, and roller) is presented in Table 4. The results showed a significant difference ($p \leq 0.05$) in moisture, ash, fat, fiber, protein, and total carbohydrates (TC) among the different milling methods. Moisture content ranged from 8.67% to 11.28% depending on the wheat variety and milling technique. Roller-milled flour consistently exhibited higher moisture values compared to flour samples milled using stone and electric-grinder methods. This could be attributed to a lower heat generated during roller milling than the other methods, which reduces moisture content. Regarding protein content, it ranged from 10.86% to 12.16%. The stone-milled flour showed the highest protein content, which could be attributed to the higher flour extraction rate (Table 2), and the higher protein content in the bran fraction (Idris et al. 2003).

Table 4. Chemical composition (%) and gluten content (%) of wheat flour extracted by various milling methods from different wheat varieties

Milling methods	Moisture	Ash	Fat	Fiber	Protein	TC	Wet gluten	Dry gluten
Gemmiza-11								
Stone	9.21 ±0.02^{c}	1.53 ±0.02^{a}	1.66 ±0.03^{a}	1.14 ±0.12^{a}	11.64 ±0.11^{a}	84.03 ±0.04^{c}	30.94 ±0.16^{a}	13.34 ±0.09^{a}
Electric-grinder	9.58 ±0.11^{b}	1.34 ±0.05^{b}	1.13 ±0.04^{b}	0.95 ±0.09^{ab}	10.86 ±0.06^{b}	85.71 ±0.06^{b}	29.72 ±0.70^{b}	12.42 ±0.15^{b}
Roller	11.28 ±0.15^{a}	1.14 ±0.02^{c}	0.85 ±0.01^{c}	0.69 ±0.06^{b}	11.44 ±0.02^{a}	85.88 ± 0.05^{a}	28.15 ±0.13^{c}	11.82 ±0.04^{c}
Giza-171								
Stone	8.67 ±0.18^{b}	1.79 ±0.02^{a}	1.88 ±0.06^{a}	1.93 ±0.05^{a}	11.73 ±0.15^{a}	82.68 ±0.18^{c}	33.80 ±0.16^{a}	14.21 ±0.18^{a}
Electric-grinder	9.00 ±0.01^{b}	1.44 ±0.05^{b}	1.77 ±0.12^{b}	1.51 ±0.09^{b}	11.24 ±0.09^{b}	84.03 ±0.07^{b}	33.23 ±0.16^{b}	13.58 ±0.08^{b}
Roller	10.84 ±0.11^{a}	1.33 ±0.06^{b}	1.64 ±0.02^{c}	0.79 ±0.01^{c}	11.59 ±0.06^{a}	84.65 ±0.14^{a}	28.25 ±0.20^{c}	11.16 ±0.05^{c}
Sakha-95								
Stone	9.58 ±0.10^{b}	1.61 ±0.01^{a}	2.14 ±0.04^{a}	2.03 ±0.02^{a}	12.16 ±0.09^{a}	82.05 ±0.07^{c}	32.54 ±0.15^{a}	13.60 ±0.21^{a}
Electric-grinder	9.87 ±0.16^{b}	1.37 ±0.02^{b}	1.91 ±0.03^{b}	1.69 ±0.09^{b}	11.48 ±0.05^{c}	83.55 ±0.18^{b}	31.38 ±0.12^{b}	13.03 ±0.10^{b}
Roller	10.31 ±0.08^{a}	1.25 ±0.06^{c}	1.72 ±0.04^{c}	0.80 ±0.03^{c}	11.73 ±0.02^{b}	84.50 ±0.01^{a}	27.60 ±0.07^{c}	12.20 ±0.11^{c}

Values are represented as means of three replicates ± SD. Values in the same column for each wheat variety separately, followed by different superscripts are significantly different ($p \leq 0.05$). Chemical composition was calculated on dry base.

The bran is the outermost part of the grain contains the aleurone layer, which is rich in protein and triacylglycerol (Tosi et al. 2011). On the other hand, the flours milled by electric-grinder had the lowest values which might be attributed to protein denaturation due

to the heat generated during this milling method. Crude fiber content was higher in stone and electric milled flour than in roller-milled one across all wheat flours. This might be related to differences in particle size distribution and bran separation. The higher protein and fiber contents of the stone-milled flour are consistent with the finding of Liu et al. (2018). Ash content, which reflects mineral concentration, ranged between 1.14% and 1.79%. Stone milling generally resulted in higher fiber and ash values across all varieties, implying a greater incorporation of bran layers in the resultant flour. Where, as the wheat bran content increases the ash content increases (Heshe et al. 2016)]. Similar observations were reported by Kihlberg et al. (2004) and Dziki et al. (2014), who found that stone milling yields flours richer in minerals and fiber due to lower bran separation efficiency compared to roller milling. In terms of fat content, stone-milled flour had significantly the highest value, which could be attributed to the presence of germ particles, which are richer in lipids (Prabhasankar and Rao, 2001). Meanwhile, during roller milling most of the germ is removed, resulting in a decreased fat content. Total carbohydrates (TC) were in the range of 82.05-85.88% and roller-milled flour showed the highest values, reflecting more refined fractions composed mainly of endosperm starch.

3.6. Gluten content

Gluten is the primary base of wheat dough, the main factor of the rheological properties of dough, and it is unique to wheat and rye. It is responsible for many of the baking properties of wheat flour. As shown in Table 4, the wet and dry gluten content of the wheat flours was significantly affected by the milling method used. This could be attributed to the different interactions of gluten proteins with the bran of different sizes (Li et al. 2023). Wheat bran consists of some active substances (such as arabinoxylan, pentosan, and enzymes) that could affect both gluten network development and structure (Noort et al. 2010; Si et al. 2021). Furthermore, milling methods influence gluten content and quality through the changes in particle size, protein interactions, and starch damage. It was reported that, gluten content of wheat flour fractions increased as the particle size decreased. For all flour samples, stone-milled flour had the highest wet and dry gluten contents, indicating a superior gluten quality which could be due to the higher protein content as shown in Table 4. Gluten and protein content of wheat flour had a significant positive correlation (Kang et al. 2019). Stone-milled flour recorded the highest wet gluten contents of 30.94%, 33.80%, and 32.54% for Gemmiza-11, Giza-171, and Sakha-95, respectively. This was followed by electric-grinder milling and then roller milling. The same trend was observed for dry gluten content, where stone milling had 13.34%, 14.21%, and 13.60% for the respective varieties. These findings reflect that stone milling maintains protein integrity and functional gluten properties better than the other two methods and stone milling can be used to produce high quality flour with superior baking performance.

3.7. Phenolic content and antioxidant activity

The whole grains benefits are contributed to the presence of functional components in the bran and germ, especially dietary fibers and phytochemicals such as phenolic compounds (Jie et al. 2020; Tariq et al. 2025). Effect of milling methods on total phenolic content (TPC) and antioxidant activity (AA) of wheat flour are represented in (Figure 1). TPC and AA values ranged from 96.68 mg GAE/100g and 5.41% to 153.44 mg GAE/100g and 6.93%, respectively. Across all wheat flour samples, there were significant differences ($P \leq 0.05$) in TPC and AA among the different milling methods. The results revealed significant differences in the TPC and AA of wheat flour depending on both the milling methods and wheat varieties. Across all wheat flour samples, flour obtained using the electric-grinder exhibited the highest TPC and AA followed by the stone-milled flour while the roller-milled flour showed the lowest values. The higher TPC and AA in flour obtained using the electric-grinder could be attributed to the severity of the grinding process, which increased the output temperature. As processing temperatures

increase, Maillard reaction products increase, which cause an overestimation in TPC (Chandrasekara and Shahidi, 2011; Carciochi et al. 2016). Regarding phenolic compounds, Liu et al. (2018) found that stone-milled flour had higher contents of protocatechuic acid, vanillic acid, epicatechin, ferulic acid, rutin, and ellagic acid, compared to roller-milled flour.

3.8. Rheological characteristics (Mixing properties)

The milling method has a significant impact on the rheological properties of wheat flour. The results of farinograph test (Table 5) revealed noticeable differences within the most farinograph properties among wheat varieties and milling methods.

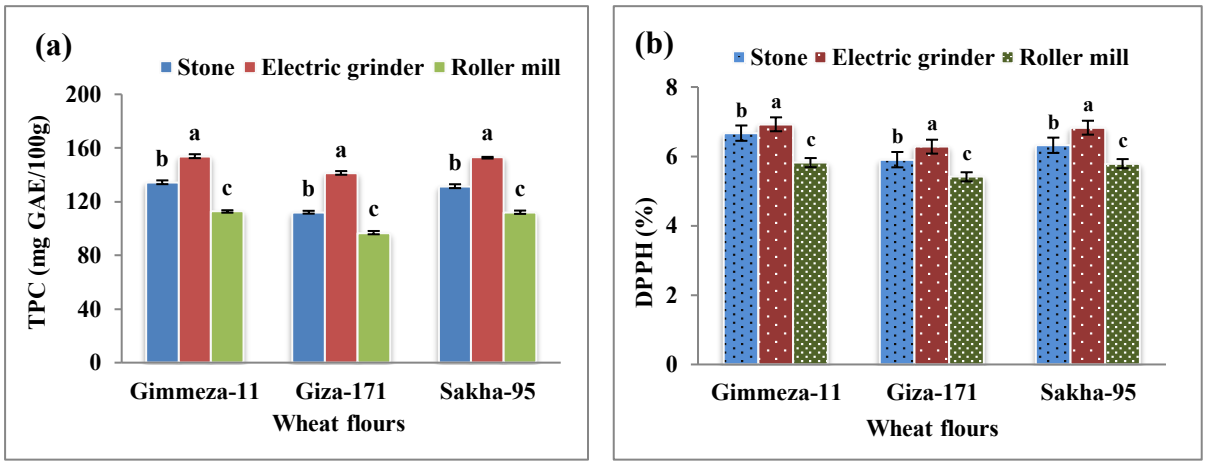

Figure 1. Total phenolic content (a) and antioxidant activity (b) of wheat flour extracted by various milling methods from different wheat varieties.

This is consistent with Alizadeh et al. (2022) who reported that, based on the farinograph properties, the wheat flour with different particle sizes showed a significant difference in the water absorption (WA, %), dough development time (DDT), dough stability time (DST), and degree of softening. Water absorption was the highest in flours obtained by stone milling for all wheat varieties (72.0%, 75.0%, and 75.2% for Gemmiza-11, Giza-171, and Sakha-95, respectively). This could be attributed to the higher fiber and bran content retained in stone-milled flour, the higher water-holding capacity (Table 3), with respect to the amount and particle size distribution (Kihlberg et al. 2004). Fibers promote water absorption as they contain a lot of hydroxyl groups, which retain water molecules through hydrogen bonds formation (Sudha et al. 2007). It was reported that the flour with particle size of 150-180µm had the highest water absorption value due to the high fiber content and pentosans in the outer layers of wheat grains (Stevenson et al. 2012). Moreover, Onipe et al. (2017) found that as wheat bran's particle size decreased from coarse bran to medium one, WA increased from 66.03% to 67.30% but subsequently declined to 65.87% for the finer bran. Furthermore, during intensive bran grinding and reduction of particle size, a breakdown of starch granules may increase, contributing to more damaged starch which enhances water absorption (Wang et al. 2020). On the contrary, roller-milled flours exhibited the lowest WA values, ranging between 58.0% and 61.8%, likely due to the removal of more bran and lower flour extraction rate.

Dough development time (DDT) is determined by the gluten network and can affect the bread quality. DDT varied among milling methods and ranged from 2 to 6.5 min. Longer DDT was observed in Gemmiza-11 variety compared to the other varieties indicating a stronger gluten network formation. This might be attributed to the finer fractions (particle size<160) in Gemmiza-11 variety compared to the other wheat varieties as shown in Table 2. Dough stability time (min) displays the time that the dough

maintains its maximum consistency and is an indicator of the dough strength (Koppel and Ingver, 2010). DST was generally higher in stone and roller-milled flour compared to electric milled one, indicating improved dough resistance to mechanical mixing. This could be due to the larger finest fraction (particle size≤160) as well as the higher protein content in stone and roller-milled flour as shown in Tables 2 and 4. Furthermore, the increased DST, which indicates the higher dough strength, could be due to increased disulfide bonds, the insolubility of glutenin polymers, and other cross-linking within the wheat proteins (Chittrakorn et al. 2014; Abdelfattah et al. 2023).

Table 5. Farinograph and extensograph parameters of wheat flour milled by various milling methods from different wheat varieties

Milling methods	Farinograph					Extensograph	
	WA (%)	Arrival time (min)	DDT (min)	DST (min)	Softening Degree (BU)	Elasticity (BU)	Extensibility (mm)
Gemmiza-11							
Stone	72.0	1.5	4.5	14.5	30	650	40
Electric-grinder	67.2	3.5	6.0	7.5	80	240	120
Roller	58.0	1.5	6.5	13.0	50	360	140
Giza-171							
Stone	75.0	1.0	2.0	4.5	100	220	80
Electric-grinder	66.1	2.0	2.5	2.0	130	140	100
Roller	61.8	0.5	2.0	4.0	110	160	105
Sakha-95							
Stone	75.2	1.0	2.0	5.0	90	260	90
Electric-grinder	72.5	1.5	3.0	2.5	110	240	95
Roller	61.1	1.5	2.5	3.0	110	160	100

WA: Water Absorption, DDT: Dough Development Time, and DST: Dough Stability Time.

Dough softening degree is an indicator to the gluten quality, describes the mixing resistance, and illustrates the viscoelastic properties of the gluten network. The increased softening degree is an index of proteolytic degradation of gluten (Abera et al. 2017). It was the lowest in stone-milled flour across the different wheat varieties, implying superior dough stability and resistance to breakdown during mixing. The higher softening in the flour milled using electric-grinder (from 80 BU in Gemmiza-11 to 130 BU in Giza-171) indicates weaker gluten structures. Among all wheat varieties, stone-milled flour had the highest elasticity (BU) while the lowest extensibility (mm) values. The choice of milling method and wheat variety significantly influence dough rheology and, consequently, end-product quality.

3.9. Sensory evaluation of bread

Bread making is a dynamic process involves Physical, chemical, microbiological, and biochemical changes caused by endogenous enzymes and microorganisms as well as thermal action (Stribiňcaia et al. 2020). The interactions between the added ingredients and the processing conditions result in the development of the sensory properties of wheat bread during the various processing stages (Haegens, 2014; Koksel et al. 2016). During baking, significant flavor compounds are produced when the Maillard reaction and caramelization of sugars and proteins in dough occur. The flavor of bread crumb is influenced by fermentation and enzymatic reactions (Mollakhalili-Meybodi et al. 2023).

Table 6. Sensory acceptability scores of balady bread produced from wheat flour milled by various milling methods from different wheat varieties

Parameters	Gemmiza-11			Giza-171			Sakha-95		
	Stone	Electric-grinder	Roller	Stone	Electric-grinder	Roller	Stone	Electric-grinder	Roller
Appearance	8.88 [a] ±0.23	8.75 [a] ±0.38	8.69 [a] ±0.46	8.38 [a] ±0.44	8.31 [a] ±0.46	8.31 [a] ±0.37	8.50 [a] ±0.53	8.44 [a] ±0.42	8.50 [a] ±0.46
Layers separation	8.75 [a] ±0.35	8.88 [a] ±0.35	8.88 [a] ±0.35	8.88 [a] ±0.35	8.75 [a] ±0.35	8.88 [a] ±0.35	8.88 [a] ±0.35	8.88 [a] ±0.38	8.88 [a] ±0.35
Crumb Color	8.38 [a] ±0.52	8.19 [a] ±0.37	8.56 [a] ±0.50	8.31 [a] ±0.46	8.19 [a] ±0.37	8.13 [a] ±0.23	8.50 [a] ±0.53	8.19 [a] ±0.84	8.38 [a] ±0.44
Crumb distribution	8.50 [a] ±0.46	8.38 [a] ±0.44	8.56 [a] ±0.50	8.25 [a] ±0.38	8.31 [a] ±0.65	8.25 [a] ±0.38	8.44 [a] ±0.50	8.31 [a] ±0.53	8.56[a] ±0.50
Crust color	8.50 [a] ±0.46	8.69 [a] ±0.46	8.69 [a] ±0.46	8.56 [a] ±0.50	8.50 [a] ±0.46	8.25 [a] ±0.38	8.44 [a] ±0.42	8.25 [a] ±0.38	8.56[a] ±0.42
Taste	8.50 [a] ±0.46	8.88 [a] ±0.35	8.81 [a] ±0.37	8.44 [a] ±0.50	8.50 [a] ±0.46	8.25 [a] ±0.27	8.50 [a] ±0.53	8.31 [a] ±0.37	8.63[a] ±0.44
Odor	8.53 [a] ±0.51	8.63 [a] ±0.52	8.81 [a] ±0.26	8.44 [a] ±0.56	8.63 [a] ±0.44	8.50 [a] ±0.46	8.75 [a] ±0.46	8.50 [a] ±0.46	8.56[a] ±0.50
Chewing ability	8.44 [a] ±0.50	8.88 [a] ±0.35	8.69 [a] ±0.46	8.44 [a] ±0.50	8.50 [a] ±0.53	8.44 [a] ±0.50	8.63 [a] ±0.52	8.44 [a] ±0.50	8.44[a] ±0.50
Overall Acceptability	8.57 [a] ±0.31	8.66 [a] ±0.27	8.71 [a] ±0.29	8.46 [a] ±0.26	8.48 [a] ±0.29	8.38 [a] ±0.23	8.58 [a] ±0.36	8.40 [a] ±0.29	8.56[a] ±0.33

Data are presented as means ± SD (n = 15). A 9-point hedonic scale was used (9= like extremely, 5= neither like nor dislike, 1= dislike extremely). For each wheat variety separately, values within each raw with the same superscripts are not significantly different ($P \geq 0.05$).

The texture of bread is resulted from multiple steps during bread making, such as development of gluten and gas nuclei inclusion, bubbles redistribution, fermentation, and baking (expansion and coalescence of bubbles) (Gao et al. 2018). Sensory attributes are important values where consumers can choose flour based on the sensory evaluation of the end product. The sensory acceptability scores of the balady bread, from different wheat varieties and milling methods, which were evaluated using a 9-point hedonic scale, are presented in Table 6. Interestingly, the obtained results revealed that there were no significant differences ($P \geq 0.05$) in all sensory attributes among different milling methods and wheat varieties. Among all bread samples, the overall acceptability ranged from 8.38 to 8.71.

3.10. Bread characterization

3.10.1. Physical and chemical properties of bread

The physical and chemical properties of balady bread prepared from flours of wheat varieties (Gemmiza-11, Giza-171, and Sakha-95) and milled by different methods (stone mill, electric-grinder, and roller mill) are presented in Table 7. Regarding color attributes of bread (crumb and crust), significant variations ($p \leq 0.05$) were observed among the milling techniques and wheat varieties, reflecting the influence of milling conditions and grain type on bread color parameters. Roller milling produced the lightest bread crust and crumb with higher L^* and lower a^* and b^* values, while milling using an electric-grinder produced darker color, more reddish and more yellow crust and crumb. Both milling technique and wheat

variety significantly influenced the color attributes of flour and bread. Regarding color attributes of crust and crumb, L^* values ranged from 67.86 to 77.98 and 61.01 to 75.58, respectively, a^* values ranged from 4.09 to 5.14 and 2.05 to 3.31, respectively, and b^* values ranged from 22.12 to 24.97 and 18.88 to 20.98, respectively. Across all wheat varieties, Gemmiza-11 and Sakha-95 exhibited higher L^* values than Giza-171, indicating slightly lighter bread color. As shown in Table 7, the milling methods had a significant ($p \leq 0.05$) impact on the weight of balady bread prepared from different flours, which varied between 134.44 and 148.56 g. Across all wheat varieties, bread produced with stone-milled flour had the highest bread weight (g), whereas bread made from roller-milled flour had the lowest weight. This could be attributed to the highest and lowest water adsorption (%) during kneading for stone and roller-milled flour, respectively as proved by farinograph test Table 5.

Table 7. Physical and chemical properties of Balady bread

Parameter	Gemmiza-11			Giza-171			Sakha-95		
	Stone	Electric-grinder	Roller	Stone	Electric-grinder	Roller	Stone	Electric-grinder	Roller
Crust color									
L^*	76.52^{b} ±0.85	74.04^{c} ±0.31	77.98^{a} ±0.30	69.21^{b} ±0.29	67.86^{c} ±0.37	71.10^{a} ±0.38	72.87^{b} ±0.37	68.86^{c} ±0.27	73.92^{a} ±0.39
a^*	4.38^{ab} ±0.33	4.95^{a} ±0.24	4.09^{b} ±0.32	4.85^{a} ±0.38	5.14^{a} ±0.18	4.67^{a} ±0.35	4.54^{b} ±0.37	5.10^{a} ±0.19	4.26^{b} ±0.09
b^*	23.31^{b} ±0.40	24.74^{a} ±0.37	22.12^{c} ±0.25	24.12^{b} ±0.26	24.97^{a} ±0.36	23.31^{c} ±0.32	23.68^{a} ±0.49	24.38^{a} ±0.69	23.19^{a} ±0.49
Crumb color									
L^*	73.11^{b} ±0.31	68.03^{c} ±0.27	75.58^{a} ±0.77	66.40^{b} ±0.67	61.01^{c} ±0.50	69.39^{a} ±0.61	70.15^{b} ±0.26	66.23^{c} ±0.61	71.92^{a} ±0.53
a^*	2.32^{b} ±0.03	2.67^{a} ±0.09	2.05^{b} ±0.22	2.81^{b} ±0.15	3.20^{a} ±0.17	2.57^{b} ±0.07	2.75^{b} ±0.14	3.31^{a} ±0.06	2.60^{b} ±0.05
b^*	19.25^{b} ±0.26	20.84^{a} ±0.29	18.88^{b} ±0.27	19.80^{b} ±0.29	20.98^{a} ±0.40	18.98^{c} ±0.32	19.34^{b} ±0.37	20.12^{a} ±0.31	18.90^{c} ±0.23
Bread weight (g)	147.76^{a} ±0.46	141.94^{b} ±0.86	136.0^{c} ±0.42	148.2^{a} ±0.96	138.14^{b} ±1.20	134.44^{c} ±1.16	148.56^{a} ±0.54	145.76^{b} ±1.03	136.01^{c} ±0.46
Chemical composition (%)									
Ash	2.50^{a} ±0.04	2.33^{b} ±0.05	2.17^{c} ±0.04	2.85^{a} ±0.06	2.75^{b} ±0.03	2.66^{c} ±0.06	2.57^{a} ±0.01	2.49^{b} ±0.02	2.23^{c} ±0.02
Fat	1.17^{a} ±0.02	1.03^{b} ±0.04	0.72^{c} ±0.05	1.48^{a} ±0.05	1.42^{a} ±0.03	0.87^{b} ±0.03	1.06^{a} ±0.01	1.02^{a} ±0.07	0.56^{b} ±0.03
Crude fiber	1.32^{a} ±0.04	1.29^{a} ±0.02	1.21^{b} ±0.06	1.49^{a} ±0.07	1.40^{a} ±0.06	1.25^{a} ±0.09	1.56^{a} ±0.05	1.42^{b} ±0.01	1.37^{b} ±0.02
Protein	12.23^{a} ±0.03	11.88^{b} ±0.12	12.15^{a} ± 0.02	12.36^{a} ±0.08	12.02^{a} ±0.13	12.24^{a} ±0.01	12.41^{a} ±0.06	12.11^{b} ±0.03	12.27^{a} ±0.03
TC	82.79^{c} ±0.06	83.47^{b} ±0.03	83.75^{a} ±0.07	81.82^{c} ±0.04	82.41^{b} ±0.01	82.98^{a} ±0.11	82.40^{c} ±0.06	82.96^{b} ±0.12	83.57^{a} ±0.02

Values are mean ± SD. For each attribute and wheat variety separately, means within the same row with different superscripts are significantly different ($p \leq 0.05$). Protein, ash, fat, crude fiber, and total carbohydrates were calculated on a dry weight basis.

As shown in Table 7, significant differences ($p \leq 0.05$) were found among both the milling methods and wheat varieties for most bread chemical components. Ash values ranged between 2.17% and 2.85%. Stone-milled bread showed the highest ash content,

followed by electric-grinder and then roller-milled samples. This pattern reflects the effect of milling extraction rate, where stone and electric-grinder milling retains more of the bran fraction rich in ash, whereas roller milling produces more refined flour with reduced ash content. Among the wheat varieties, Giza-171 bread exhibited the highest ash values (2.66–2.85%). Fat content ranged from 0.56% to 1.48%, with stone-milled flours consistently had higher fat values across all milling methods. This is attributed to the inclusion of the wheat germ and aleurone layer during stone milling. Roller-milled flours showed the lowest fat values (0.56 – 0.87%). Giza-171 bread sample recorded the highest fat content, particularly with stone mill and electric-grinder (1.48% and 1.42%, respectively). Crude fiber and protein contents ranged from 1.21% to 1.56% and from 11.88% to 12.41%, respectively. The highest fiber and protein contents were found in stone-milled breads. Total carbohydrates content ranged from 81.82% to 83.75% and roller-milled breads had the highest TC, while stone-milled breads recorded the lowest across all bread varieties. Overall, the milling method significantly influenced the nutritional profile of the resulting balady bread. Stone milling retained higher ash, fat, and fiber contents, while roller milling increased TC content due to higher refinement.

3.10.2. Moisture loss and staling rate (%) of bread

Regarding the moisture content of the bread, the obtained results showed that the moisture content significantly ($p \leq 0.05$) decreased with increasing storage duration up to 72 hrs (Figure 2a). This decrement could be due to the starch retrogradation in the bread matrix causing migration of the moisture outward (Wang et al. 2025). The moisture content of bread samples on the first day of baking (zero time) ranged from 35.41 and 37.13% which steadily declined to reach its maximum loss (from 30.30 and 32.10%) after 72 hrs. The stone-milled bread had the highest moisture content, followed by electric-grinder and then roller miller one. The Alkaline Water Retention Capacity (AWRC, %) test was used as an indication of the freshness of bread. A higher AWRC value indicates greater the water binding capacity, a lower staling rate, and a higher freshness of the bread. Bread staling is a complex process involves a combination of physical change as moisture migration and chemical amylopectin retrogradation and recrystallization leading to crumb hardening and a reduction of quality (Najafabadi et al. 2014). Figure 2b shows the staling rate (%) of bread prepared with various milled flours after different storage durations (24, 48, and 72 hrs) at room temperature. Data revealed that the staling rate (%) significantly ($p \leq 0.05$) increased during storage periods up to 72 h. These results may be due to moisture loss by evaporation and moisture redistribution between crust and crumb. Across different wheat varieties and milling methods, staling rate was in the range of 20.32-30.25%, 35.99-45.81%, and 38.78-49.42% after 24, 48, and 72h of storage, respectively. Additionally, stone-milled bread had the lowest staling rate among each wheat variety, which could be attributed to the higher moisture and protein content as shown in Figure 2a and Table 7. Flours with higher protein content absorb more water. Staling rate and bread firming are dependent on moisture content, and bread with more water staled slower (Scanlon et al. 2000; Pizza and Masi, 1995). Salehifar et al. (2010) found that the staling rate in breads prepared from flour with high protein quality and quantity was delayed. Milling methods influence bread staling by changing the properties of flour, through the damaged starch content and different particle size, which affect the starch-water interactions which cause staleness (Wang et al. 2025; Mete et al. 2021).

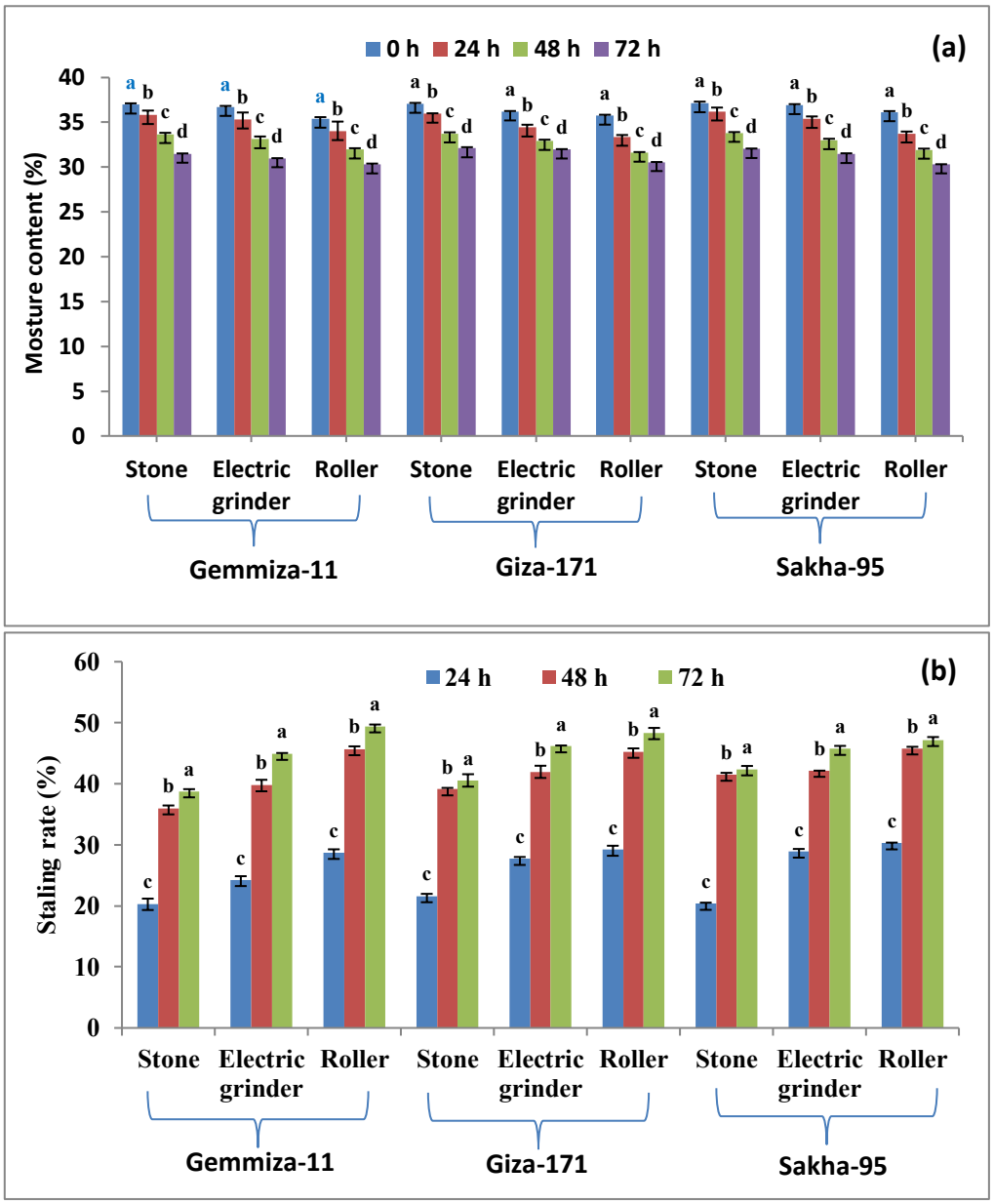

Figure 2. (a) Moisture loss (%) and (b) staling rate (%) of Balady bread during storage for 24, 48, and 72 h at room temperature.

4. Conclusion

Milling methods have a significant impact on the physical and chemical, functional, and nutritional properties of highly extracted wheat flour. Among the studied methods, stone milling produced flour with the highest extraction rate, nutritional, and functional performance due to the larger incorporation of bran and germ fractions. This method enhanced water absorption, gluten strength, and dough stability, leading to bread of superior texture, higher moisture retention, and slower staling during storage. Roller milling, although yielding lighter flour and bread, resulted in lower protein, fiber, and ash content. Electric-grinder milling increased total phenolic content and antioxidant activity while caused partial thermal degradation of flour components. Despite differences in composition and functional characteristics, sensory evaluation revealed no significant differences in overall acceptability among breads from the three milling methods. Consequently, stone milling is a viable method for creating nutritionally rich flours with appropriate technological properties for functional and bakery applications, meeting customer demand for healthier and less refined

wheat-based foods. Future research should focus on assessing the effect of storage duration and conditions on the quality and stability of the highly extracted wheat flour produced by different milling methods. Which could be essential to optimize shelf life and preserve the nutritional value of highly extracted and whole grain flour intended for bakery products.

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